BODY WEIGHT AS A MOTIVATING OPERATION:
The Effect of Body Weight on Demand for Food in Hens.

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Abstract

Demand for wheat and puffed wheat was examined in six hens, using an ascending geometric progression of fixed-ratio schedules of reinforcement. Hens responded by pecking a key for 2-s access to food in 40-min sessions. The body weight criterion used to decide if a hen was to be placed in an experimental session differed across conditions, to determine if this would affect performance, using wheat and puffed wheat as reinforcers in different conditions. In the first experiment the hens were maintained by post-session feeding at 80 ± 5% of their free-feeding body weights. In Conditions 1 and 2 the hens were placed in a session even when they were more than 5 % above the target weight. In Conditions 3 and 4 they were placed in a session if their body weight was within the specified range, meaning there could be several days between sessions.

There were clear differences resulting from food type, both in behaviour under the fixed ratio schedules, and in the resulting demand functions (with consumption measured as either number of reinforcers or weight of food obtained). Wheat resulted in lower overall response rates than puffed wheat at low fixed ratio values. The body weight criterion did not result in large effects on performance, however, the more relaxed body weight criterion gave a higher essential value for puffed wheat than for wheat (replicating Foster et al., 2009), whereas, the strict body weight criterion gave a lower essential value for puffed wheat than for wheat under the analysis proposed by Hursh and Silberberg (2008) and using number of reinforcers as the consumption measure.

A second experiment replicated Jackson (2011), using the same two foods, strict body weight criteria and sessions which terminated after 40 reinforcers or 40-min. The resulting data were similar to Jackson (2011), who

found similar performance for both foods. The difference between the demand functions for the two foods, with reinforcer rate as the consumption measure, were greatly reduced in comparison to Experiment 1. The essential value of the two foods was not consistently different across hens. These results suggest that the session termination criterion did affect demand.

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Table of Contents

List of Figures

List of Tables

Introduction

Fixed-Ratio Schedules

Many studies have used increasing fixed-ratio schedules to assess demand for food reinforcers in animals (e.g. Crossman, Borem, & Phelps, 1987; Foster, Blackman, & Temple, 1997; Felton & Lyon, 1966; Cassidy & Dallery, 2012). In a fixed-ratio (FR) schedule of reinforcement, a reinforcer is delivered after a specified number of responses (Ferster & Skinner, 1957). After each reinforcer is delivered, the number of responses required by the participant/subject is reset. The study of demand may present multiple FR schedules across sessions, where the response requirement increases (e.g. Johnson & Bickel, 2006; Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988).

Previous studies of animal behaviour under FR schedules have examined the response rates, and the length of the pause after each reinforcer. The overall response rate is calculated by dividing the number of responses made in the session by the total response time. Research has shown that lower FRs tend to have higher response rates rather than higher FR values (e.g. Crossman et al., 1987; Foster et al., 1997). For example, an animal on an FR2 schedule — where reinforcement is delivered after every second response — has a higher response rate than the same animal on an FR 200 schedule (Crossman et al., 1987). Animals responding under increasing FR schedules are likely to have higher response rates at low FR values, and lower response rates at higher FR values (Crossman et al., 1987).

Foster, Blackman and Temple (1997) also found that as ratio requirements increase, overall response rates decrease. Factors that influence the overall response rates are session length and economy type as per Foster et al. (1997). For example, they found that longer sessions in a closed economy — where the food was only available was during experimental session — resulted in overall response rates increasing alongside increasing ratio requirements (Foster et al., 1997).

A post-reinforcement pause (PRP) in responding is typical on an FR schedule. A PRP is defined as a short pause in responding directly after receiving reinforcement (Ferster & Skinner, 1957). The average PRP length is the total PRP duration in a particular session, divided by the number of reinforcements obtained. A PRP is typically followed by a high and consistent rate of responding until the FR requirement is met (Lattal, 1991). The rate of responding in this period is known as the running response rate. The average running response rate for a session is calculated by the number of responses, divided by the total time, minus the PRP time. Ferster and Skinner (1957) argued that as the ratio requirement increases, the running response rates decrease, and the pause lengths increase. A decrease in the response rate as the FR schedule increases has been evident in various studies such as those by Jackson (2011), Lim (2010), and Foster, Sumpter, Temple, Flevill, and Poling (2009).

Felton and Lyon (1966) examined response rates and PRP lengths under FR schedules using pigeons. These pigeons were trained to peck a key on a continuous reinforcement schedule (FR 1) which was increased to FR 25. Once a stable rate and pattern of responding was established across all pigeons, Felton and Lyon (1966) increased the ratio requirement gradually from FR 25 up to FR 150, at increments of 25 responses. Felton and Lyon (1966) found that as the ratio increased, there was a general decrease in the overall rate of responding, and an increase in pause lengths. They found that pauses also occurred within bouts of responding, meaning that pauses in responding were not only found immediately following reinforcement. This finding — that pause length had a negative influence on the rate of responding — led to Felton and Lyon (1966) concluding that both types of pauses should be investigated as two dependent variables that change as the ratio requirement increases.

Demand

When investigating demand for a commodity, particularly with animals, the experimenter may vary the effort requirement through changing the FR schedules, and then analysing the changes in consumption of that commodity. The data can then be plotted, with the Y axis showing consumption of the commodity and the X axis showing the increase in the fixed-ratio response requirement — an analogue of 'price' — producing a demand curve.

Hursh (1980) suggests that demand for reinforcement can vary in elasticity. Elasticity indicates the degree to which the amount of reinforcement (obtained through responding) increases or decreases with corresponding changes in price; this is known as demand. Hursh (1980) discussed four types of demand: inelastic demand, unit demand, elastic demand and demand of mixed elasticity. Dawkins (1988) suggested that by examining elasticity of different commodities, the results can provide researchers with a measure of value for different reinforcers.

The slope of the function generated gives an indication of the elasticity of the demand at various points along the curve (Hursh, 1984). Figure 1 shows how changes in price (P) can affect consumption (Q) and response rates (R). The left column depicts changes in consumption (Q) in response to changes in price (P), whereas the middle column shows the changes in response rate (R) to sustain the consumption rate. The last column, on the right-hand-side, shows the demand function produced by logarithmic co-ordinates (log Q vs. log P), giving the elasticity co-efficient (EC) as the measure of elasticity (Hursh, 1980). The amount of elasticity is represented by the slope of the demand function, produced by consumption of the commodity over price. Elastic demand is represented by a slope of +1 or higher. In contrast, slopes with an elasticity co-efficient of -1 or lower depict inelastic demand (Hursh, 1980). Elasticity of demand can be viewed as a continuum, with elastic demand and inelastic demand at either end.

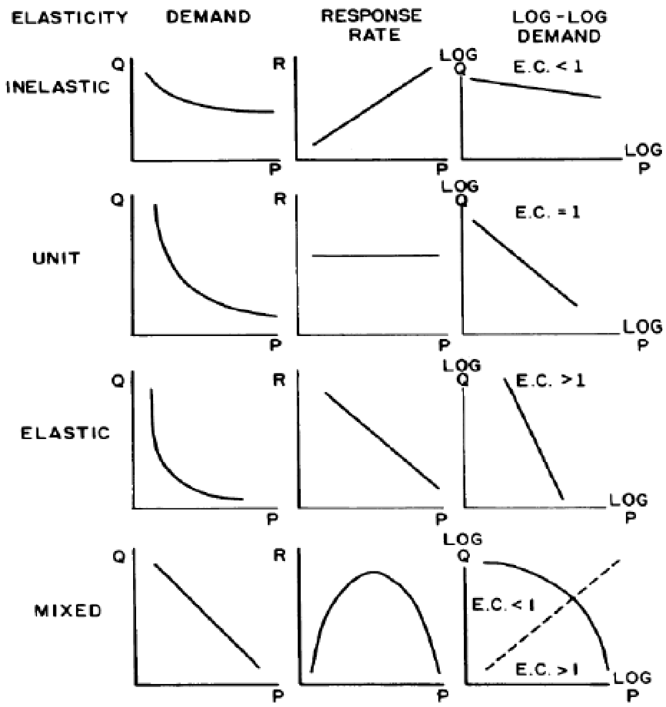

Figure 1. The four types of elasticity of demand, response rates and elasticity co-effecients plotted in log-log co-ordinates. Reproduced from “Economic Concepts for the Analysis of Behavior” by S. R. Hursh, 1980, *Journal of the Experimental Analysis of Behaviour, 34*, p. 227. Copyright 1980 by John Wiley and Sons. Reprinted with permission.

Demand is said to be inelastic when the price increases, but consumption does not change to the same degree (Hursh, 1984). A typical demand curve indicative of inelastic demand would show a relatively shallow decreasing demand curve, as shown in the top right graph of Figure 1 (Hursh, 1980). Elastic demand occurs when the response-cost increases whilst consumption decreases. This is often seen when the commodity is considered a luxury item (Hursh, 1984).

A steep decrease in demand in response to the price increasing, as seen in the third row of graphs of Figure 1, shows elastic demand (Hursh, 1980). Commodities are not as highly valued when the demand is elastic compared to those that show inelastic demand (Hursh, 1984).

Unit elasticity is seen when the function has an elasticity co-efficient (EC) that is equal to 1, as seen in the third graph, second column, of Figure 1. Unit elasticity refers to situations in which the effort used to obtain the commodity stays constant in response to changing the ratio requirement (Hursh, 1980). Therefore, as the response-cost increases, the subject continues responding at the same rate and thus less reinforcement is obtained.

The relationship between consumption and price is not always linear, as illustrated in the bottom row of graphs in Figure 1. Mixed elasticity is characterised by a downward curve (as in the last graph of Figure 1) where first part of the demand function is inelastic (trending downwards with a slope of less than -1), and last part is elastic (depicting a slope steeper than - 1). For reinforcers with mixed elasticity, inelastic demand is thus seen at smaller ratios, but becomes elastic at higher ratio values, producing a curvilinear function.

Mixed elasticity can be a result of bitonic response rate function (Hursh, 1980). This means that the rate of responding initially increases as price increases, with the rate of responding peaking at a particular price before decreasing as price continues to rise. Responding does not cease, as shown in the last graph, middle column, of Figure 1. Bitonic response rate functions are often seen in behavioural economics research. Alvey (2000), for example, found a bitonic response rate function with two qualitatively different reinforcers, in a study on demand with humans. The aim of that research was to compare the demand functions for both monetary and sound reinforcers in four human participants. Demand was less elastic for money than it was for sounds. Demand for sounds decreased to a greater degree than the demand in the money contingency, however, both reinforcers were shown to decrease in response rates, then increase, showing a bitonic output for both reinforcer types. Similar bitonic functions have frequently been found in animal research (e.g. Foltin, 1992, 1994; Hursh, 1984; Foster et al., 2009; Jackson, 2011).

Hursh, Raslear, Shurtleff, Bauman and Simmons (1988) propose the following equation to describe mixed elasticity demand curves using natural logarithms:

$$\ln Q = \ln L + b\,(\ln P) - aP \qquad (1)$$

where Q represents consumption, P represents the price or ratio requirement, and L, a and b are the fitted parameters. The parameter L is the approximate consumption of reinforcers where the price is 1 (the lowest price) and b is the initial elasticity at this price. The deceleration of the slope, with increases in price, is represented by a (Hursh et al., 1988).

Foltin (1991) investigated demand using the non-linear function when he examined baboons' demand for banana flavoured pellets. This involved altering FR values from FR 2, FR 4, FR 8, FR 16, FR 32, FR 64, FR 96, to FR 128 and then repeating the presentation of these values in reverse. The amount of food earned was plotted against the price (FR value) and the above equation, Equation 1, was fitted to the data. Results showed that the demand was inelastic. At majority of the FR values, the baboons showed increases in response rates. Eventually the FR value became too high for the baboons to complete the necessary ratio requirement in the 22 hour session. This resulted in a decrease in consumption. Foltin (1991) concluded that the aforementioned equation (Hursh et al., 1988) for non-linear data described the data well. Foltin (1991) therefore acknowledged that the response rates increased substantially, before decreasing, to show the curvilinear trend. He argued that perhaps researchers should investigate the maximum response rate whilst analysing demand.

The price associated with the maximum response output value is known as P_{max} (Hursh & Winger, 1995). At this value, the demand changes from inelastic to elastic, and the elasticity co-efficient is thus equal to 1 (Hursh & Winger, 1995). The equation for P_{max} is as follows (Hursh & Winger, 1995):

$$P_{max} = (1 + b) / a \qquad (2)$$

The parameters a and b are defined as they are in Equation 1. It is suggested that the P_{max} value can be used to examine the value of the reinforcer thus giving an indication of the effort a subject will expend to gain the commodity used as reinforcement. If the P_{max} value is higher for one reinforcer over another, then it can be determined that the reinforcer associated with a higher maximum response output holds more comparative value to the subject.

Although, Equation 2 provides the maximal response output value, it only gives a single point on the demand curve. Hursh and Silberberg (2008) therefore suggested an alternative equation to give an indication of the entire decline across a demand curve. This equation is presented below:

$$\log Q = \log Q_0 + k\,(e^{-\alpha p} - 1) \qquad (3)$$

Here, Q_0 gives an approximation of the highest amount of consumption, when price is as low as possible. This is comparable to L in Equation 1. The parameters P and Q are the same as they were in Equation 1. The parameter k gives the range of consumption, and α represents the change in consumption as price increases. Hursh and Silberberg (2008) argued that α specifies the essential value of the reinforcer, while k is the scaling parameter. This is set constant across conditions so that changes in elasticity can be observed by changes in the alpha (α) parameter. A larger α value reflects increasing elasticity, meaning the reinforcer has less essential value, and produces a steep demand curve. Hursh and Silberberg (2008) believe this equation is superior to Equation 1 (Hursh et al., 1988) because it provides the same information, using a single parameter (α) to show the elasticity of demand and gives an indication of the essential value of a commodity.

Hursh et al., (2013) note that variables which change the scalar value of the reinforcer, such as the size of the reinforcer, dose, potency, and utility of the reinforcer, should not change the essential value of the reinforcer. As the essential value does not change, the α value should be the same, regardless of the size or the amount of the reinforcer.

The elasticity of the demand for a commodity is determined by the economic context as a whole. According to Hursh (1984), there are multiple variables that can alter elasticity. These include the intensity of demand, the nature of the reinforcer — i.e. whether the reinforcer is a necessity or luxury (e.g. Matthews & Ladewig, 1994) — the species of the subject, as well as the availability of substitutes for the reinforcer, and the type of economy meaning whether the commodity is available from other sources (open economy) or not (closed economy).

The intensity of demand is controlled by two main variables, the level of deprivation or satiation of the subject, and the magnitude of the reinforcement (Hursh, 1980). Deprivation refers to the restriction of the commodity being accessed, which increases the subject's motivation to respond for the reinforcer, known as the concept of an establishing operation (EO) or motivating operation (MO) (McGill, 1999; Michael, 2000). When satiation occurs, the essential value of the reinforcer changes, and there is a decrease in motivation to work for the item. Satiation therefore, changes the shape of the demand function produced. Establishing operations have two main effects; the first being the reinforcer efficacy (potency), and the second being, the change in the rate of the response behaviour (Michael, 2000).

The context in which the reinforcer is available, in particular the type of economy used, also influences the slope of the demand function (Hursh, 1980). In a closed economy, there is no alternative option other than to respond for the reinforcement offered (Hursh, 1984). This affects demand because it means that commodity can only be gained through responding in the experimental session i.e. there is no external source of reinforcement available (Hursh, 1980). An open economy offers the option to not respond on the schedule because there is an external source for the commodity. For example, in a laboratory setting, subjects are often allowed supplemental food after an experimental session to ensure health and weight are maintained (Hursh, 1980). The post-session feeding means the experimental session operates as an open economy as the commodity (food) can be assessed outside the session.

Ladewig, Sorensen, Nielsen and Matthews (2002) investigated the differences in demand functions produced under an open and a closed economy, in rats responding under fixed-ratio (FR) schedules. They found that the rats worked harder in a closed economy for water as reinforcement when this was the only opportunity for the rats to receive water. In the open economy the demand functions were steeper, whereas in the closed economy, the demand function was significantly shallower (Ladewig et al., 2002). This research supports the notion that animals working in a closed economy for a necessity will exhibit more inelastic demand for the commodity, as opposed to showing elasticity of demand when working in an open economy. This idea has implications for the applicability of behavioural analysis, as it shows that when the reinforcers can be otherwise obtained (an open economy), the demand will be significantly reduced, subsequently affecting the behavioural response associated with obtaining that commodity (Ladewig et al., 2002).

Alongside the type of economy used, researchers have found that the type of food can also affect demand. Using concurrent schedules of reinforcement, researchers established the preferences of six hens for three food types (Foster, Sumpter, Temple, Flevill & Poling, 2009). The food types available were wheat (W), puffed wheat (PW) and honey puffed wheat (HPW). The results showed that W was the most preferred food. The researchers compared demand for the reinforcers by using a series of increasing FR schedules, and comparing the results across the different food types. It was found that consumption — measured by the number of reinforcers obtained — was highest for the most preferred food (W), but only at higher FR values (Foster et al., 2009). At low FR values the initial consumption for HPW and PW was higher than for the most preferred food (W). However, responding rates decreased steeply with price for both HPW and PW (Foster et al., 2009). These results indicate that food is an important factor in determining the slope of the demand function.

Another important aspect to consider in the analysis of demand is motivating operations (MOs). Motivating operations alter the effectiveness of the reinforcer, and evoke responses that are associated with obtaining reinforcement (Michael, 1999).

One variable that has been investigated as an MO is body weight. Ferguson and Paule (1997) researched the effect of body weight on behaviour working under progressive-ratio (PR) schedules. They varied the body weights between 70 – 100% of the rats' free-feeding body weights. The rats had to press a lever a number of times to gain reinforcement, with the number of responses required increasing after each reinforcer. Ferguson and Paule (1997) examined three aspects of the rats' behaviour: the response rates, the number of reinforcers earned — and subsequently the FR value at which the sessions terminated at, known as the break point — and the post-reinforcement pause length. They found that overall response-rates decreased, as body weight increased, thus there was also a decrease in consumption (Ferguson & Paule, 1997). Additionally, they noticed an increase PRP length. Here, behaviour under the PR schedules did show differences across body weight, indicating body weight worked as a MO in rats (Ferguson & Paule, 1997).

The effect of diet as an MO has also been examined. Elia, Erb and Houpt (2010) tested how hard horses would work to obtain hay when they were fed a pelleted diet with low fibre. To investigate this, they examined the demand for a high fibre diet (i.e. demand for hay). Elia et al. (2010) found that horses would respond more for pellets than they would when they received hay as their diet. The study concluded that there were differences in demand when the horses were fed the different diets which was attributed this to the fibre content of the maintenance diet. The fibre content was thus working as an MO affecting the demand for hay (Elia et al., 2010).

Maintenance diets have also been investigated as an MO in birds. Jackson (2011) examined the effects of maintenance diet type on demand for food in hens. Using progressive ratio schedules (PR), she assessed the demand for different types of feed. The hens were placed in a session only when they were within target weight range (80 ±10 %). Although Jackson used the same foods as Foster et al. (2009) she found conflicting results. Jackson (2011) found the demand functions were very similar regardless of the type of food used as reinforcer or as the maintenance diet. In case this was the result of using PR schedules, rather than the FR schedules, used by Foster et al. (2009), Jackson (2011) also investigated demand using FR schedules. In order to make sure the hens required supplementary feeding, the number of reinforcers per session was limited across the smaller FR values, and sessions were terminated after 40 reinforcers or 40 minutes, whichever happened sooner. The results showed that regardless of the type of schedule, there was no difference between the feeds in the demand functions.

Jackson (2011) pointed out that her experimental procedures differed from Foster et al.’s (2009) in several ways. One was the criterion for the session termination, as Foster et al. (2009) used 40-min sessions. Also, Jackson’s (2011) hens always got some supplementary food between sessions, making the sessions an open economy. Foster et al. (2009) gave supplemental food only when body weight dropped, mainly at the larger FR values. Jackson (2011) also had stricter body weight criteria for her sessions, while Foster et al.'s (2009) hens were not given supplementary feeding when overweight, but were still placed in experimental sessions. Therefore, in Foster et al.'s (2009) research, hens could obtain large numbers of reinforcers at low FR values, and therefore the hens could have been at higher body weights than at the large FR values where fewer reinforcers were obtained. Although, it was clear that the type of reinforcer and maintenance diet did not alter demand in Jackson's (2011) study, it was not clear why the demand differed from that found previously. Jackson (2011) argued that given body weight had been shown to be an MO by Furgeson and Paule (1997), that it would be worth investigating whether the way body weight was controlled in her experiment (80 ± 10%) that was the reason her results did not replicate those of Foster et al. (2009). As Foster et al. (2009) did not report the degree of weight variations over their experiment, an experiment that did so whilst comparing results using strict body weight control is needed.

Cassidy and Dallery (2012) examined rats responding on increasing FR schedules (FR 1, 5, 10, 20, 40, 80, 160, 320, 640, 1280) for access to one or two pellets of food. They compared demand under open economy sessions that ran for 130 minutes, and provided supplementary feeding where required, to closed economy sessions which ran for 23 hours with all food consumed in the experimental session. There were differences in the way body weight was handled in the closed and open economy sessions. In the open economy sessions, rats were given post-feed when required, to maintain weight at approximately 85% of their free-feeding body weight, and they were not placed in a session if overweight. In the closed economy session, there was no post-feed offered therefore body weights could vary. Between series of the FR sequence, the procedure states that rats were removed from experimental conditions for three days, wherein weight was stabilised back to approximately 85% of the free-feeding body weight. Body weight control was similar to Jackson (2011) in the open economy, yet more similar to Foster et al. (2009) in the closed economy sessions. They found differences in the demand curves from the two session types, with the two different amounts of feed. The rats gained more reinforcers at small FRs from the one pellet conditions compared to the two pellet conditions. Using Hursh and Silberberg's (2008) analysis, the essential value should not have differed between the one and two pellet conditions, as these are scalar differences. However, they found that essential value was lowest for the two pellets and highest for one pellet under the open economy. This was an unexpected finding, but the difference in essential value was not statistically significant under the closed economy. Cassidy and Dallery's (2012) study therefore showed that the demand functions were affected by either the different body weight control, or by the different economy types, or by both. It requires a separate analysis of the effects of body weight control and economy type to see which affects the demand functions.

The aim of the present research is to investigate whether controlling body weight would explain the differences found in the results from Foster et al. (2009) and Jackson (2011). This investigation will determine whether quantifiably different demand functions for two food types (W and PW) will be produced, using Hursh et al.'s (1988) equation. A second aim of the present study is to fit Hursh and Silberberg's (2008) equation to the demand data, to see how essential value is affected by the way body weight is controlled, when one food is preferred to the other. In a previous experiment, preferences were assessed in five of the six hens. The results showed that wheat is the more preferred reinforcer, compared to puffed wheat (Schroeder, 2013). Preference is therefore not examined in this study.

Between the different feed types, it is expected that overall rates of consumption of W will be higher than PW; the initial consumption of PW is expected to be higher but decrease more rapidly once the FR schedules increase based on the findings from Foster et al., (2009). It is also hypothesised that breakpoints will be higher in W conditions compared to PW conditions. P_{max} values also also expected to be higher in W conditions compared to those for PW.

Furthermore, it is expected that there is a decrease in consumption, at increased body weights like those of Ferguson and Paule (1997). It is therefore expected that under hens are under strict body weight control, they will consume less, regardless of food type.

Experiment 1

Method

Subjects

This experiment used six Brown Shaver hens (*gallus gallus domesticus*) numbered 111 to 116. All hens had prior experience in experimental conditions. Hens 111 to 115 had experience pecking an infrared computer screen and all six had experience pecking plastic keys for food under concurrent schedules of reinforcement. The hens were weighed daily and their weights were maintained by supplementary feeding of commercial laying pellets. They were run when they were approximately 80% of their free feeding body weight. They were housed in individual cages which were 310mm high, by 440mm wide, and 450mm deep, in which they had free access to water.

Apparatus

The experimental chamber measured 540mm high, by 540mm wide, and 620mm long. The interior, which was made of particle board, was painted white. There was one round response key (30mm in diameter) in the chamber, 330mm above the chamber floor in the centre. This key was made from translucent Perspex, which could be lit up green. The key was surrounded by a rectangle of aluminium which was approximately 70mm wide and 140mm long. The key required a peck with the force of 0.1N to close a micro-switch located behind the key, which was followed by a brief audible beep. Beneath the key, there was an opening measuring 100mm high by 70mm wide which provided access to the food hopper. Additionally, a sensor was used to record when the hens' head entered the magazine opening and a catch tray placed beneath the magazine to collect any spilt food. The magazine rested on an Atrax BH-3000 digital scale. A computer was attached to an interface unit. This was located in the same room and ran the MedPC program which ran and recorded each session.

Procedure

In a series of conditions, the hens responded to gain 2-s timed access to food. The hen would peck the illuminated key for the required FR value and then receive reinforcement. Reinforcement would be signalled by the key light turning off and the light of the food hopper turning on and food hopper raising. During this period any pecks would not be recorded or counted towards the next reinforcement. The food hopper was raised for 2-s timed from when the hen broke the sensor beam in the opening to the food hopper.

After 2-s access the food hopper would be lowered so the hen would no longer have access to food and the key would be re-illuminated. The response-requirement must then be met again for access to reinforcement. The computer software recorded all experimental events and a summary of this data was recorded manually following each session in a data book.

Each session lasted for 40 minutes where an effective key was presented. Session duration was not contingent on the number of reinforcers obtained and excluded magazine operation time. The experimental sessions were held daily between 7am- 3pm. On lower FR values (FR 1, 2, 4 and 8) the hens were run three per day because the sessions could be very long.

In all conditions the hens were exposed to a geometric progression of FR values (FR 1, 2, 4, 8, 16, 32, 64, 138, 256, 512, 1024) until no reinforcers were delivered in a session. If no reinforcers were obtained during a session, the hen would be exposed to that particular FR value again. In the next session, that FR was represented. In the representation, if no reinforcement was obtained again, that was considered to be the end of that series, however, if reinforcement was delivered, the sequence would continue in the following session until two consecutive days of no reinforcement at which point the series was then stopped. Following a series, the hen was exposed to an FR 40 schedule for at least three days. The food presented during these FR 40 sessions, was contingent on the food that was being provided in the next experimental series, either W or PW.

In Condition 1 hens were placed in the experimental chamber regardless of weight, where they were responding for W. FR schedules were presented one per session in an ascending order starting at FR 1 and followed a geometric progression. Following this the hen was exposed to the FR 40 for several sessions (minimum of three sessions), then the progression started again. Two series were completed in this condition.

In Condition 2, PW was the food hens were responding for. The hens were also run regardless of weight. There was also two series of ascending FR schedules presented followed several sessions of FR 40.

Condition 3 was the same as Condition 1 except the hens were only run if they met the target body weight criteria. The weight requirement for this condition was 80 ± 5% of their free-feeding weight. Again, they were presented with a series of ascending FR schedules, one per session and W was placed in the magazine. Due to time constraints, three of the six hens completed two series in this condition and the remaining three hens completed only one series in this condition.

Condition 4 was identical to Condition 3 except the food the hens were reinforced with was PW. Only one series was completed in this condition.

Results

The summary data from each experimental session in each of the four conditions are presented in the Appendix, located inside the back cover.

Breakpoints

The FR values at which each series terminated for each hen, are presented in Table 1. The asterix on Table 1 indicates where data collection was abandoned, due to time constraints, so these values do not reflect the natural breakpoint and thus subsequently excluded from further analyses of breakpoints. All hens stopped between FR values 128 and 1024, with the majority of breakpoints being either FR 512 or FR 256.

There were two series of the ascending FR schedules completed in Condition 1 and Condition 2. Five of the six hens completed one series in Condition 3, and two of these completed two series. In Condition 4, only one series was conducted which all six hens completed.

It appears that there were no consistent differences in the breakpoint in the two series completed during Condition 1 and Condition 2. Four of six subjects terminated the series at larger FR values in Condition 1, where W was the reinforcer, than Condition 2, where PW was the reinforcer. Similar values were seen in the two W conditions, Conditions 1 and 3, where there was a difference in the body weight controls. There were no differences in the breakpoints for the two PW conditions (2 and 4) for all hens.

Table 1. The last FR value presented in the series before the hen ceased responding for all six hens across all four conditions in Experiment 1.

	Condition 1 W		Condition 2 PW		Condition 3 W		Condition 4 PW
111	512	512	256	512	512	1024	512
112	512	512	256	512	512	512	256
113	512	1024	512	512	512	NA	512
114	256	512	512	256	512	16*	512
115	256	512	512	512	32*	NA	256
116	512	128	128	256	256	NA	256

Response Rates

The overall response rates were calculated as the total number of responses per session, divided by the key time (2400-s). Key time is defined as the total session time, excluding the time which in the magazine is operative. Figure 2 shows the overall response rates for each hen, in each condition, plotted against natural logarithm of the FR value for each series in Conditions 1 to 4, respectively.

Response rates typically increase, peak, and decrease again. Each graph in Figure 2 shows this typical pattern, with no consistent differences noted across the series, where two series were completed. There were also no consistent differences in the pattern of response rates across hens.

Figures 3 - 6 show all possible comparisons of the average overall response rates. These graphs compare W with PW, where the body weight criteria are relaxed (hens run regardless of weight), and strict (where the hens' body weight must be within the target range). Comparisons were also made between the two W conditions, and the two PW conditions. Figure 3 shows the comparison between Condition 1 and Condition 2 (W vs. PW). Figure 4 compares Conditions 1 and 3 (both W), showing the difference in the overall response rates for different body weight criteria. Figure 5 compares Condition 3 and 4 (W vs. PW). Figure 6 compares the differences between Conditions 2 and 4 (both PW). There are no significant differences between the averages for each condition.

Figure 3 shows higher response rates for the PW condition (Condition 2) than the W condition, at low FR values. The response rates then decrease in both conditions but Condition 1 (W) then shows higher response rates per minute at higher FR values compared to Condition 2 (PW). Figure 4 shows no consistent difference in the two W conditions where body weight criteria was strict, meaning hens had to be within the target weight criteria in Condition 3 compared to Condition 1 where the weight requirement did not need to be met. Figure 5 shows similar results to Figure 3; the response rates are higher for PW (Condition 4) than they are for W (Condition 3) for low FR values. Figure 5 also showed that once response rates decrease W had a higher response rate compared to the condition in which PW was available at higher FR values. Figure 6, like Figure 4, shows no consistent difference in the response rates per minute for the six hens in the two PW conditions.

In summary, the overall response rates were higher for the PW conditions over the W conditions at low FR values, but at higher FR values, W had higher response rates compared to PW. There were no consistent differences between the conditions which had different body weight criteria.

Running response rates were calculated by dividing the number of responses made in the experimental session, over the total time, minus the post-reinforcement pause time. It is not possible to calculate the running response rate at FR1, because the run time is the same as the key time, so this was excluded from the following graphs. The running response rate (s) has been plotted against the natural logarithm of the FR schedule. Figure 7 shows the running response rates for each hen. The left column shows the two series completed in Condition 1. The middle-left column shows the two series in Condition 2. The middle-right column shows Condition 3, and the far-right shows Condition 4. All of these graphs show that typically the running response rates decreased as the FR values increased for all hens. There were no consistent differences across the two series, and therefore the averages were used for comparisons.

The running response rates appeared to decrease more steeply in the PW conditions (Conditions 2 and 4), compared to conditions where W was the reinforcer (1 and 3).

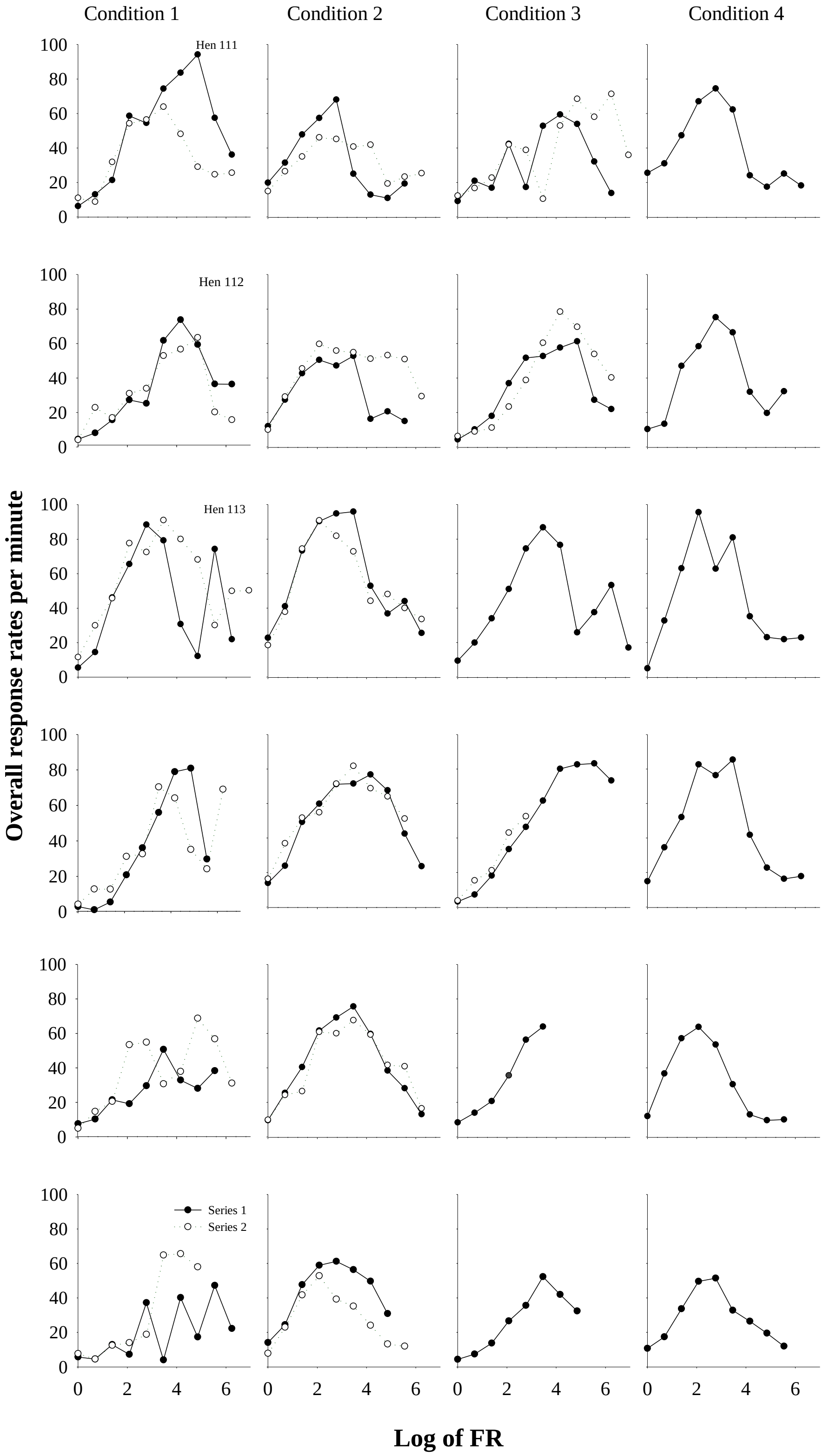

Figure 2. This graph shows the overall response rates for FR schedules for each hen across all four conditions.

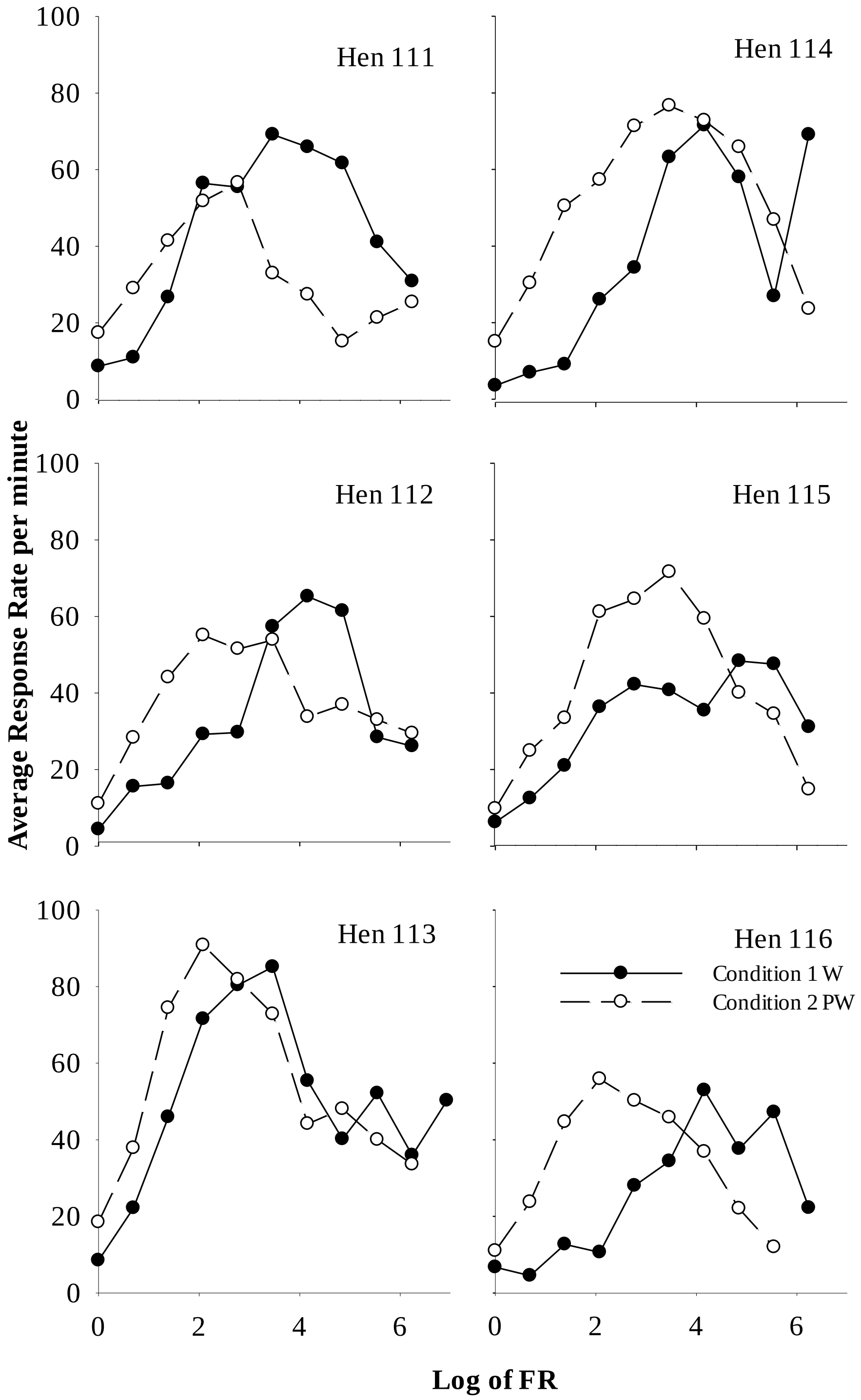

Figure 3. This graph shows the overall response rates for FR schedules for each hen across Conditions 1 and 2.

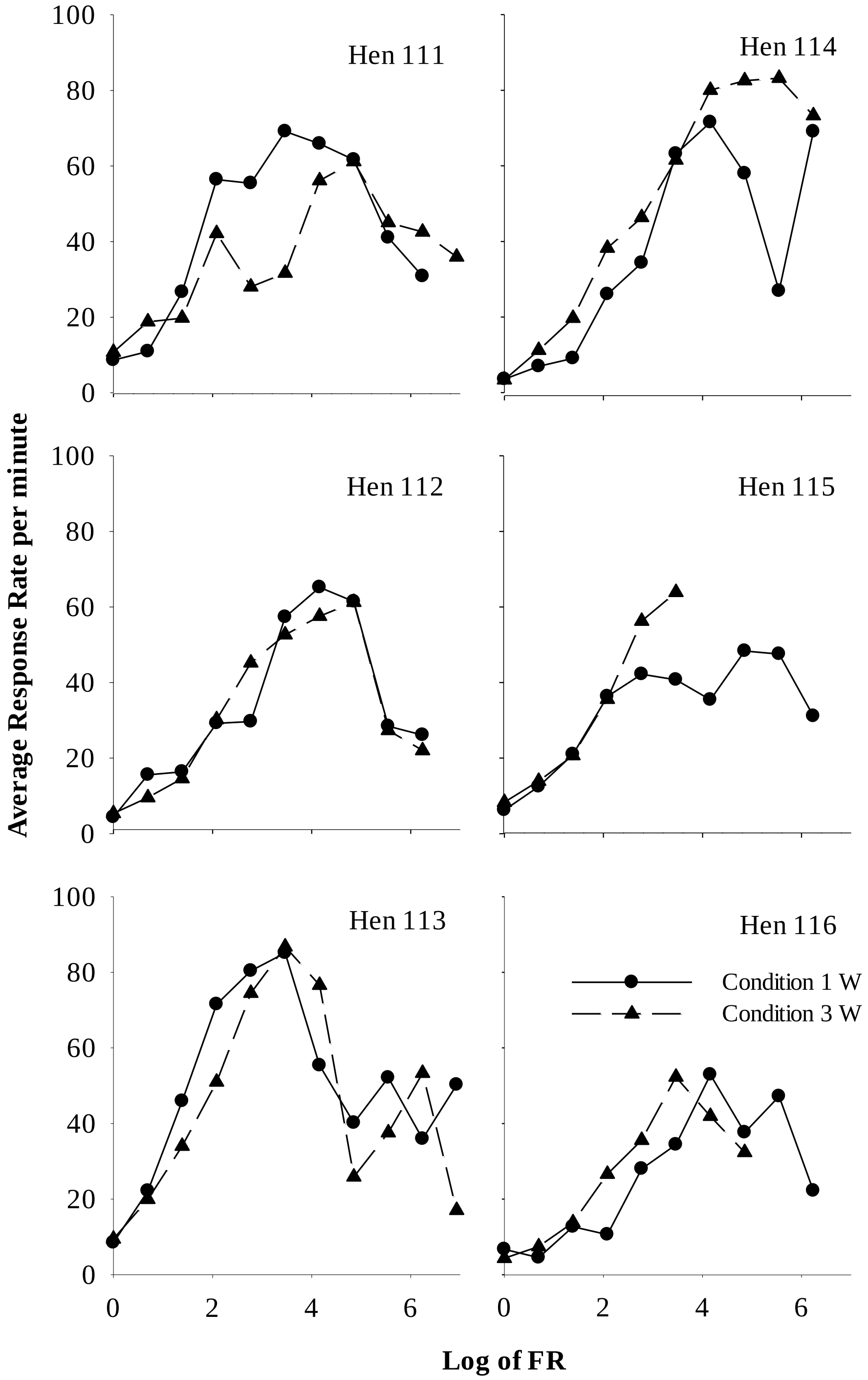

Figure 4. This graph shows the overall response rates for FR schedules for each hen across Conditions 1 and 3.

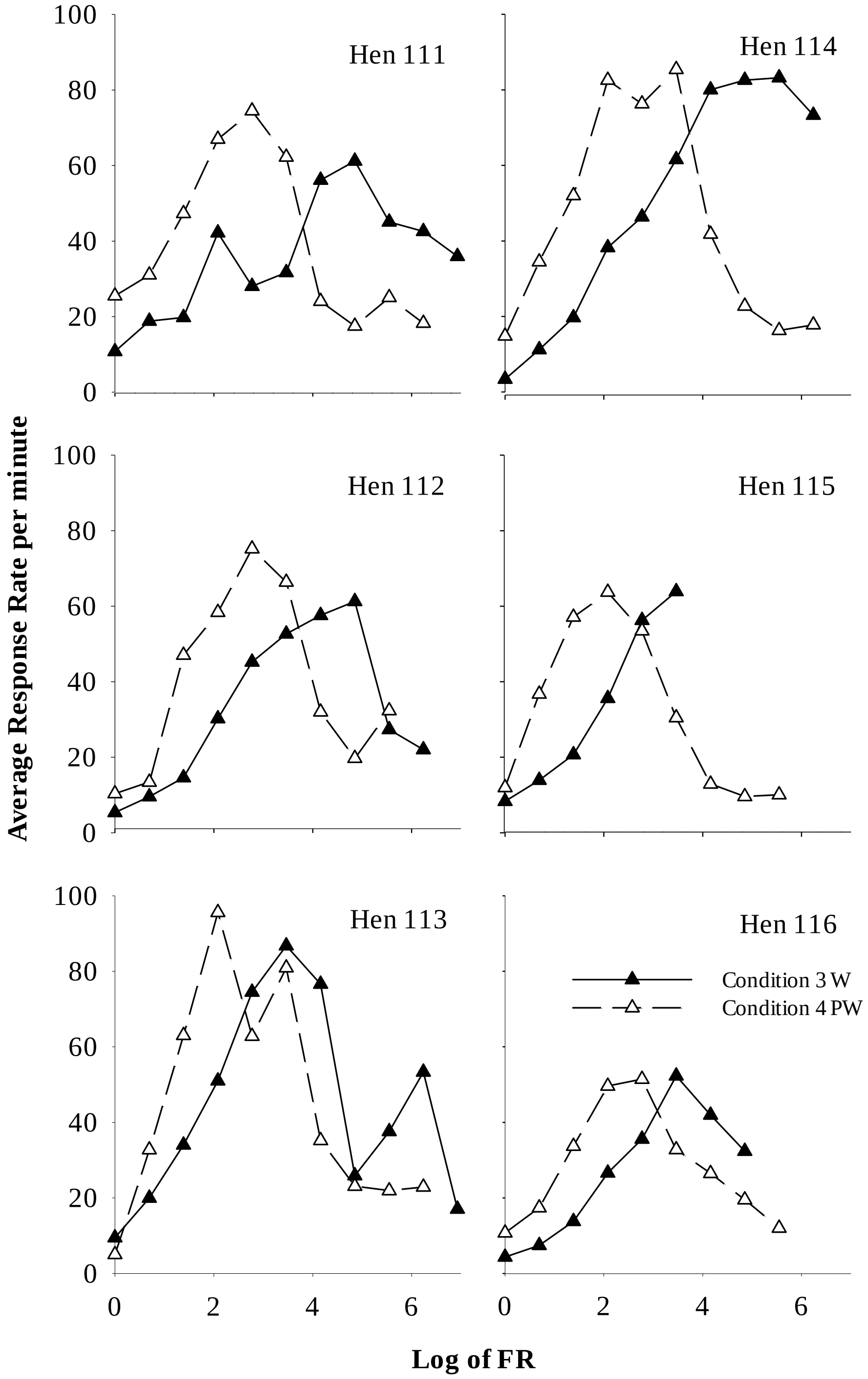

Figure 5. This graph shows the overall response rates for FR schedules for each hen across Conditions 3 and 4.

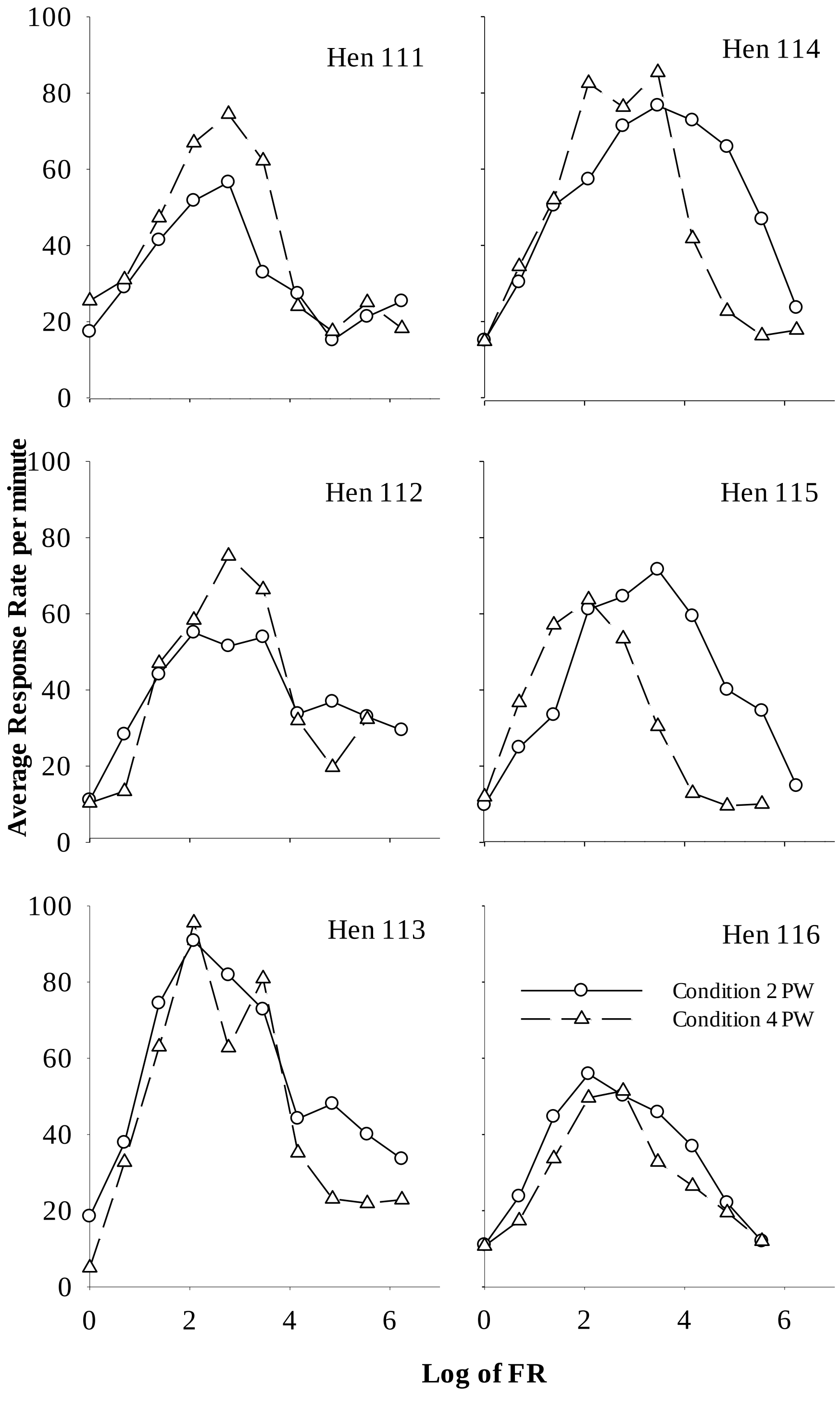

Figure 6. This graph shows the overall response rates for FR schedules for each hen across Conditions 2 and 4.

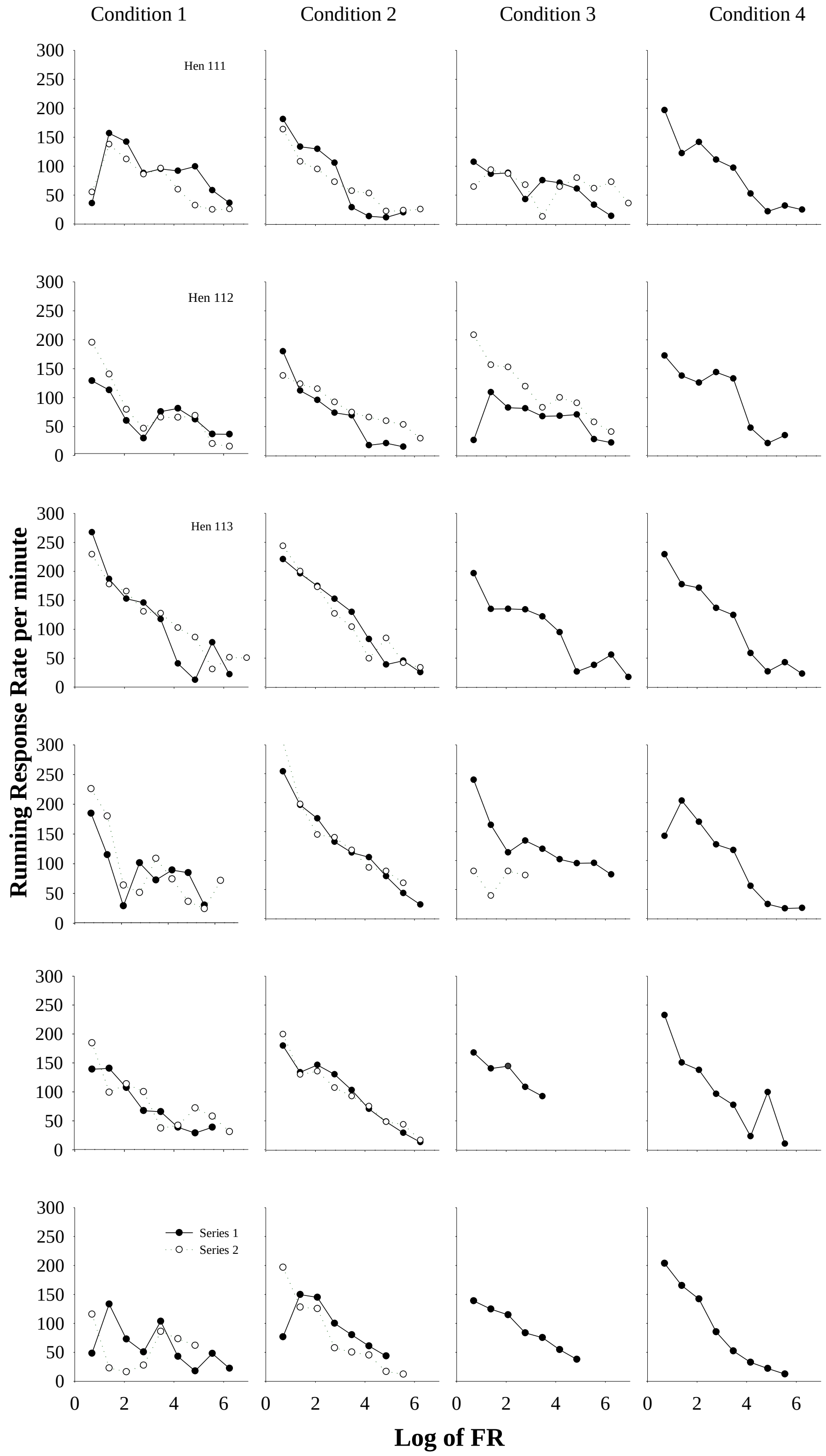

Figure 7. This graph shows the running response rates for FR schedules for each hen across all four conditions.

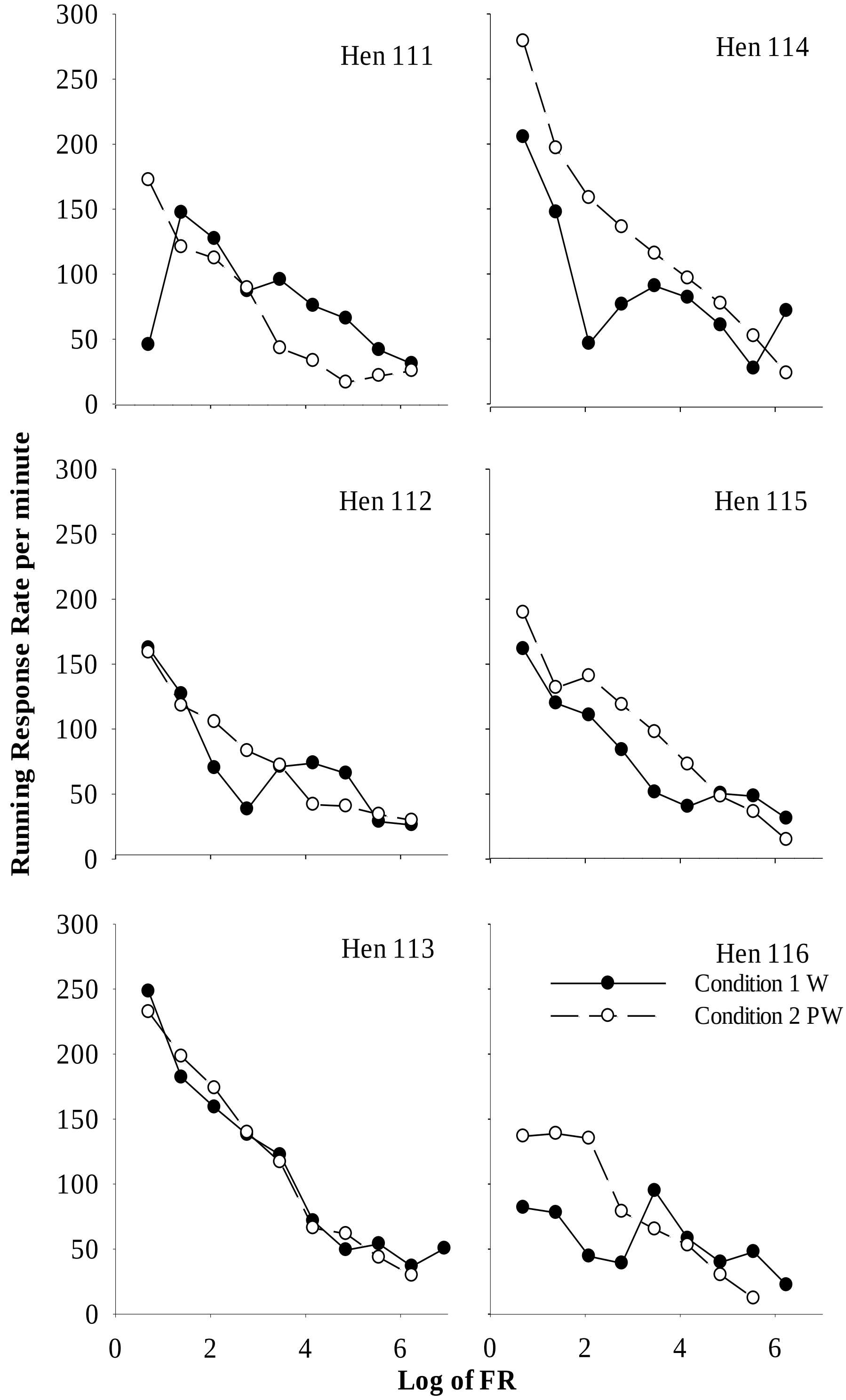

Figure 8. This graph shows the running response rates for FR schedules for each hen across Conditions 1 and 2.

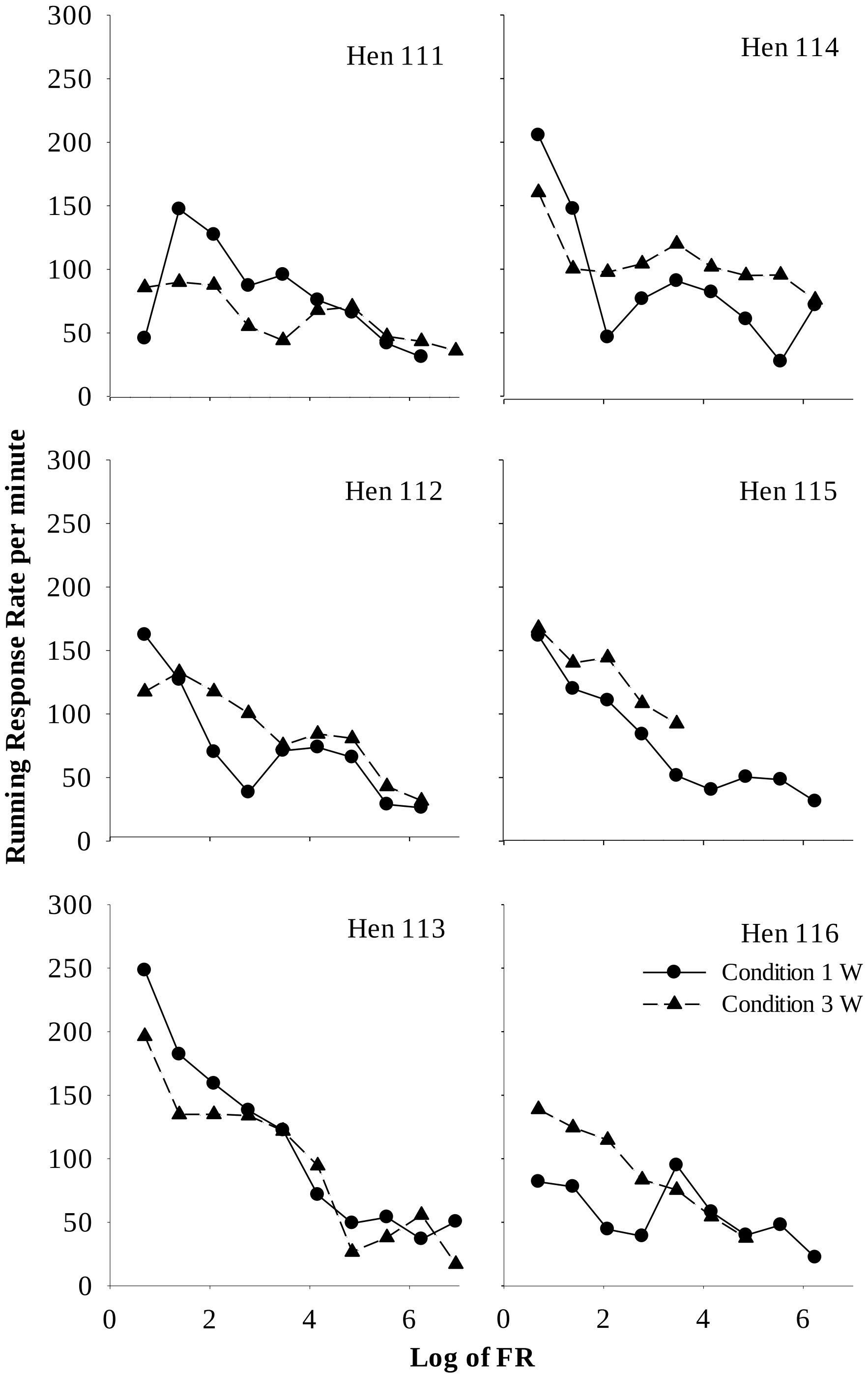

Figure 9. This graph shows the running response rates for FR schedules for each hen across Conditions 1 and 3.

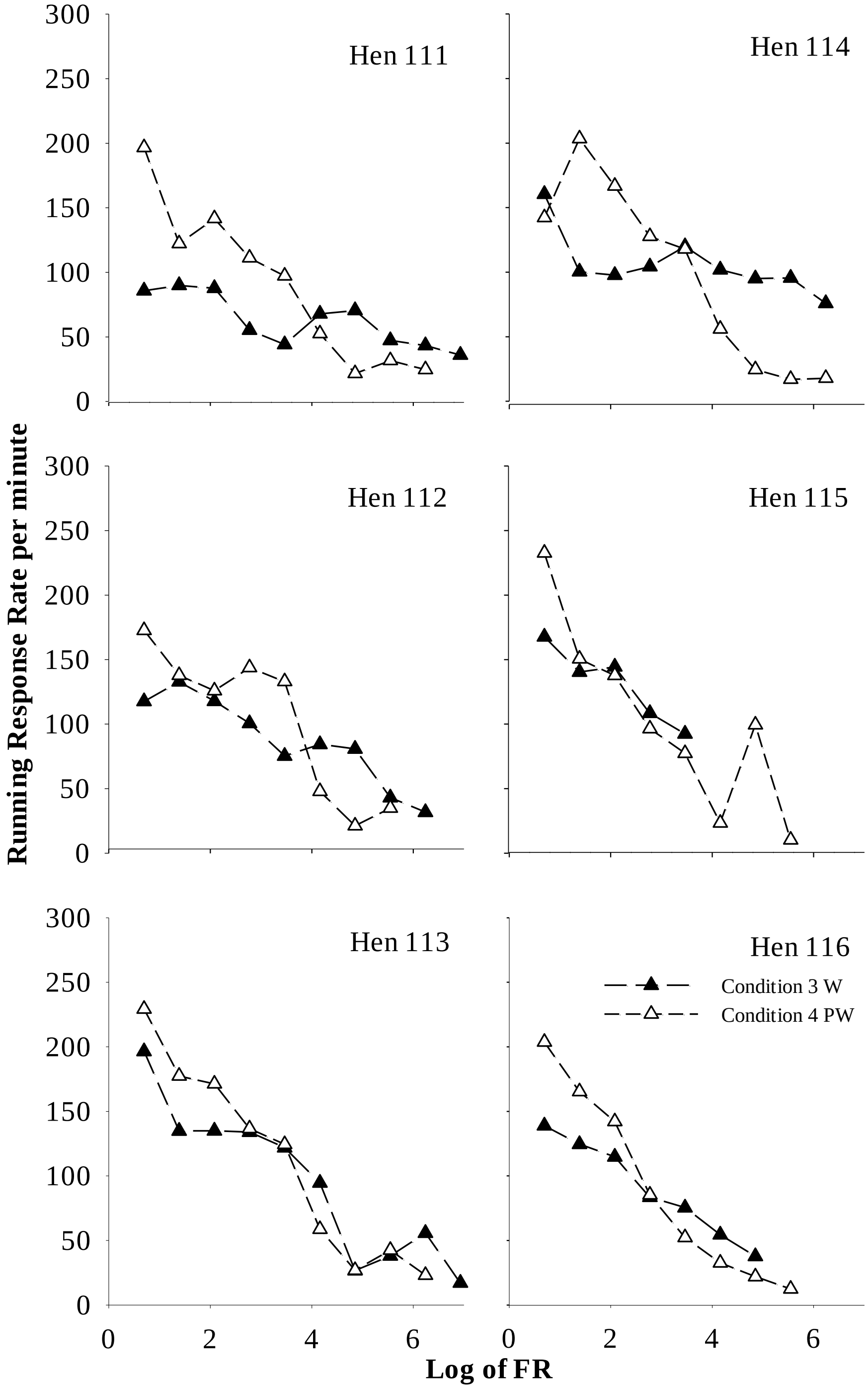

Figure 10. This graph shows the running response rates for FR schedules for each hen across Conditions 3 and 4.

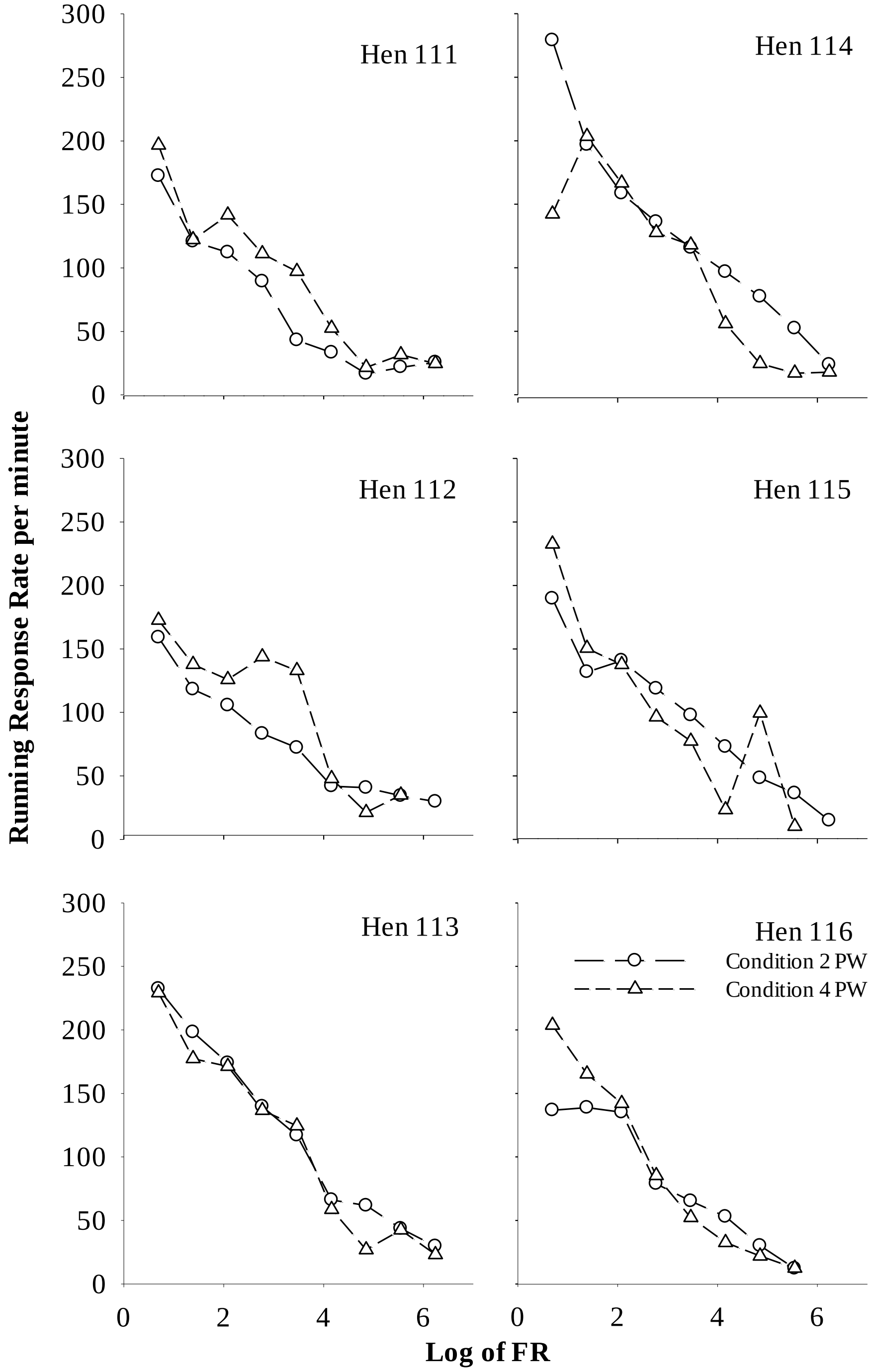

Figure 11. This graph shows the running response rates for FR schedules for each hen across Conditions 2 and 4.

Figure 8 shows the comparison between Condition 1 and 2, whereas Figure 10 shows the comparison between Conditions 3 and 4. Figure 8 shows the running response rates were higher for PW (Condition 2) than they were for W (Condition 1) for low FR values. Figure 8 also shows that W had a higher running response rate than PW, at higher FR values. Figure 10 also shows this pattern between W and PW. Figure 9 shows the comparison between the two W conditions (1 and 3), and Figure 11 shows the comparison between the two PW conditions (2 and 4). There were no consistent differences between the running response rates seen in either comparison between Conditions 1 and 3, or Conditions 2 and 4.

In summary, the running response rates decrease as the FR value increases. Running response rates decreased more steeply for PW than W. There were no consistent differences between the conditions which had different body weight criteria.

Post-reinforcement pauses

Data on the PRP lengths were also collected and analysed. PRP is the latency period from when the reinforcement delivery has ceased, and the stimulus (key light) has reappeared, to the first following response after reinforcement. The average PRP duration across the entire session, is obtained by dividing the total duration of pause time, by the number of reinforcers obtained.

Figure 12 shows the average PRP duration, plotted against the natural logarithm of the FR value for Conditions 1 – 4. Figure 12 shows that the average PRP length was typically found to be less than 20 seconds at lower FR values before an increase was seen at higher FR values.

In Conditions 1 and 3, the average PRP lengths are generally very short, and were also relatively stable. There is some variability in the pause lengths, in hens 114 and 116. In Conditions 2 and 4, there was an increase in pause lengths toward the end of the series. There were no consistent differences across the series for any condition.

Figures 13 – 16 show all possible comparisons from the averages of the series completed for each condition between food types and body weight control. Figures 13 (comparing Conditions 1 and 2) and 15 (3 and 4) show that the average pause length for PW is slightly shorter than that of W, at low FR values. Figure 16 shows that the average pause length for PW appeared to be less than 10 seconds for the first 6 FR values (FR1, 2, 4, 8, 16 and 32) before increasing to above 20-s in five of six hens in Condition 2, and all six hens in Condition 4. Figure 14 shows that this increase was not as noticeable in conditions where W was the reinforcer (Condition 1 or 3). There was some increase in the pause lengths, for two hens in Condition 1. Hen 116 also showed an increase in the average PRP duration at FR32, but following this the pause lengths decreased for the following FR values, to below 20-s in length. This was therefore seen as an outlier. In Condition 3, hen 111 showed an increase in pause lengths then a decrease as the FR value increases. An increase in PRP length was also seen in three hens. Figure 14 shows no systematic difference in pause lengths between the two W conditions, however, a considerable difference is seen between the two PW conditions (2 and 4) in Figure 16. The PRP lengths seen in Condition 4 were higher at high FR values in the condition where there is strict body weight control.

In the W conditions, the pause lengths were typically very stable showing little variability compared to PW, where some extreme pause lengths are seen.

There were no differences between the conditions that had relaxed, and strict body weight controls when hens responded for W. The average PRP length was longer for PW in Condition 4, where body weight was strict, than in Condition 2 where body weight was relaxed.

Demand

One way consumption was assessed was to graph the natural logarithm of the number of reinforcers obtained, against the natural logarithm of the FR value. Figure 17 shows the consumption of reinforcers for each condition. In all conditions the data showed curvilinear demand with initial inelasticity before demand became elastic at high FR values. There appeared to be no consistent differences across the two series in Condition 1 (far-left column of Figure 17). There were also no differences in the two series in Condition 2 (middle-left column of Figure 17). The two hens that completed two series in Condition 3 also showed no differences (middle-right column of Figure 17). Only one series was completed in Condition 4 as illustrated in the far-right column of Figure 17.

As there were no differences between two series in the conditions, where two were run, the averages of each condition were compared together, against those of other conditions. Figures 18 - 21 show all possible comparisons. Figure 18 shows that there was some difference in number of reinforcers obtained in Conditions 1 and 2, with hens obtaining more PW reinforcers than W, at the smaller FR values. However, there was some tendency for this difference to be reversed at a higher FR value. The crossover point differs across hens.

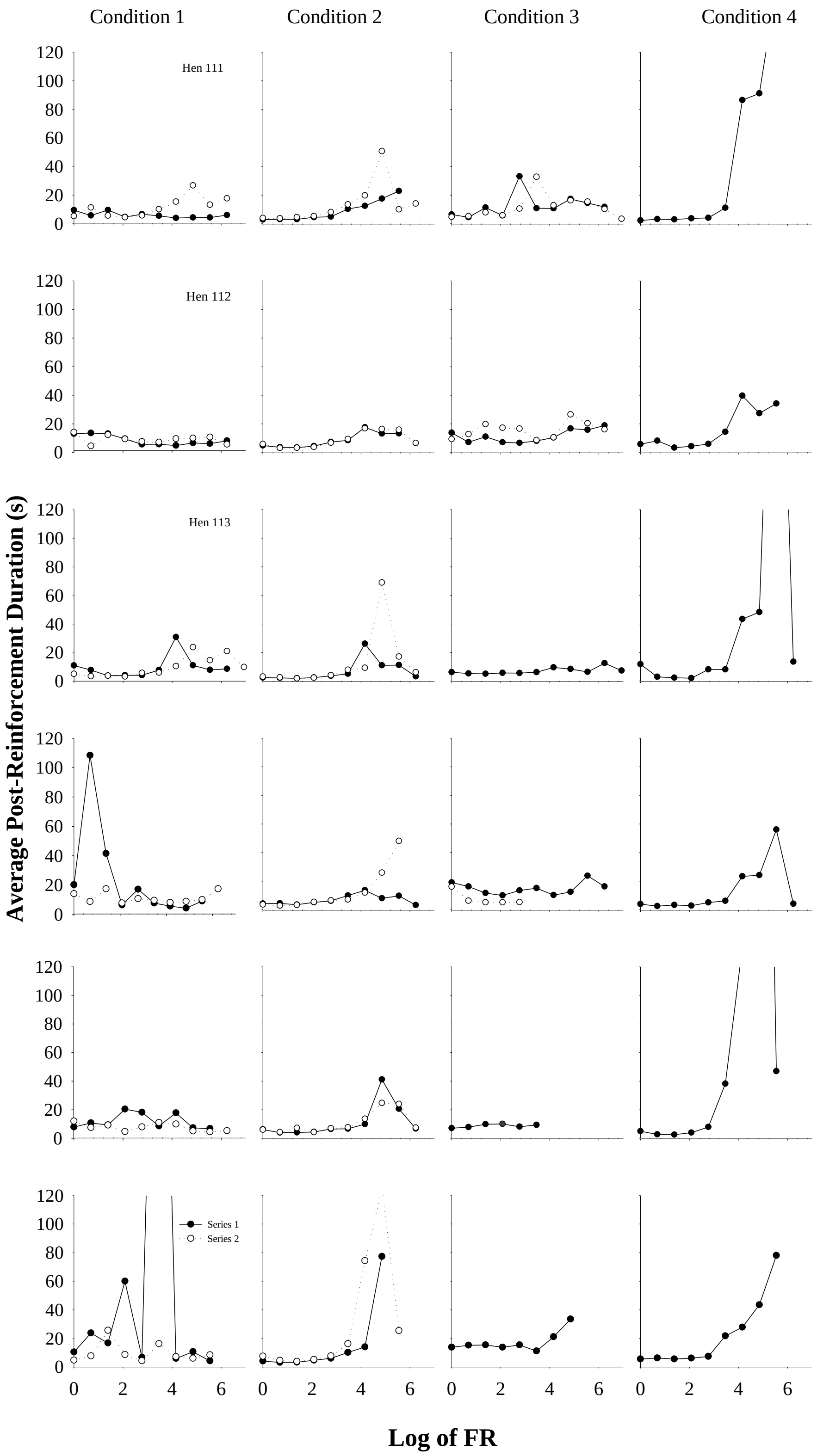

Figure 12. This graph shows the average PRP duration for FR schedules for each hen across all four conditions.

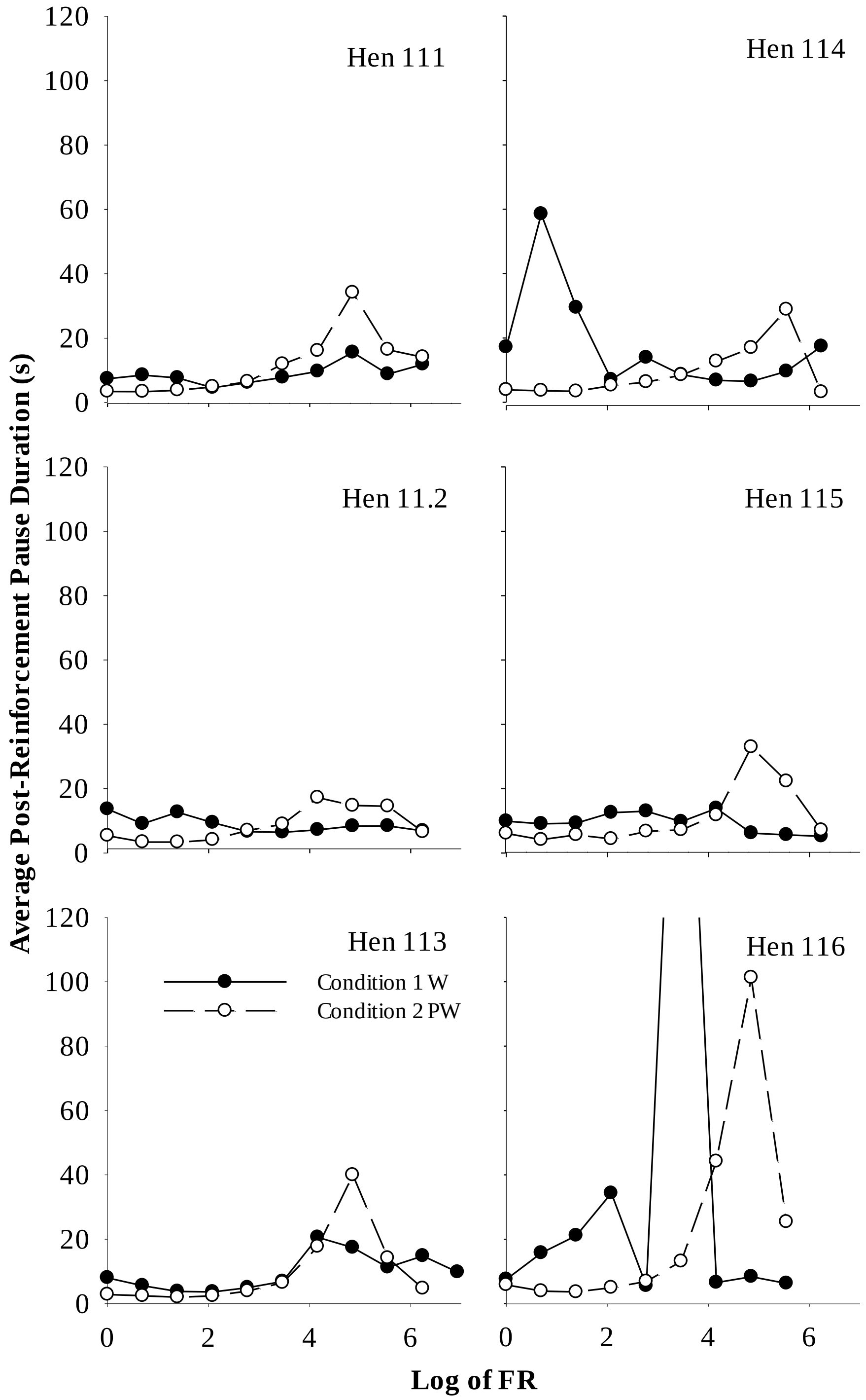

Figure 13. This graph shows the average PRP duration for FR schedules for each hen for Conditions 1 and 2.

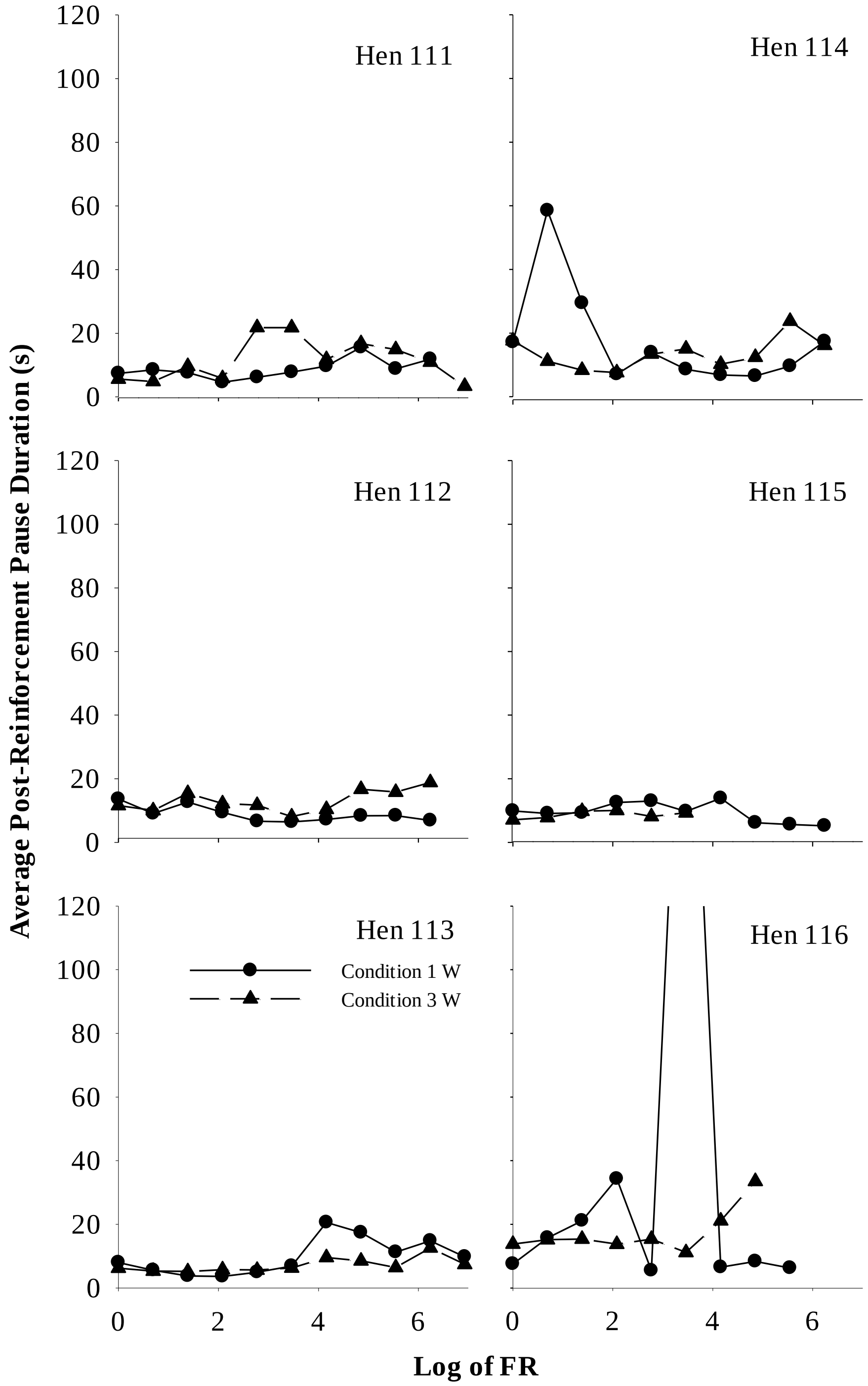

Figure 14. This graph shows the average PRP duration for FR schedules for each hen for Conditions 1 and 3.

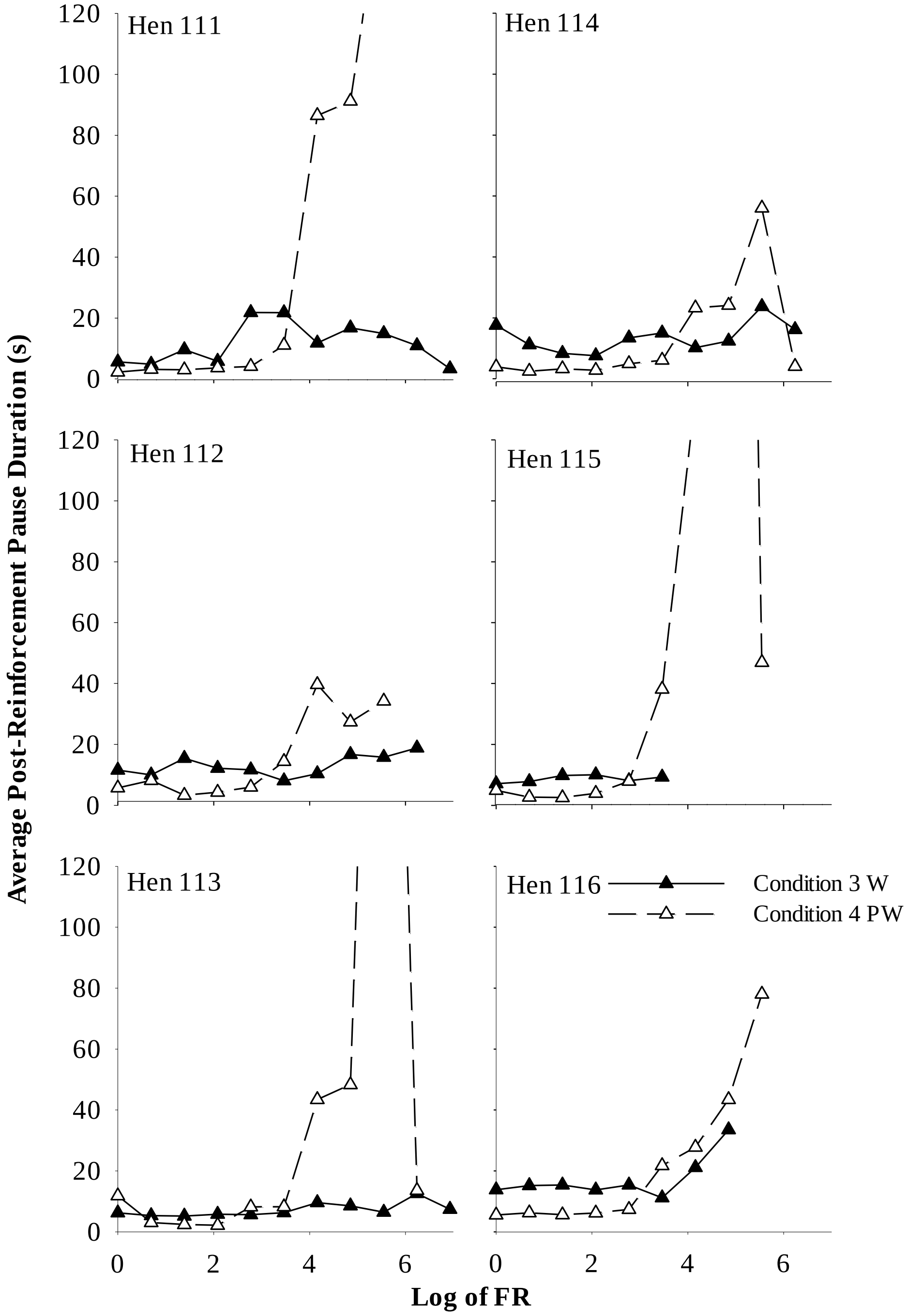

Figure 15. This graph shows the average PRP duration for FR schedules for each hen for Conditions 3 and 4.

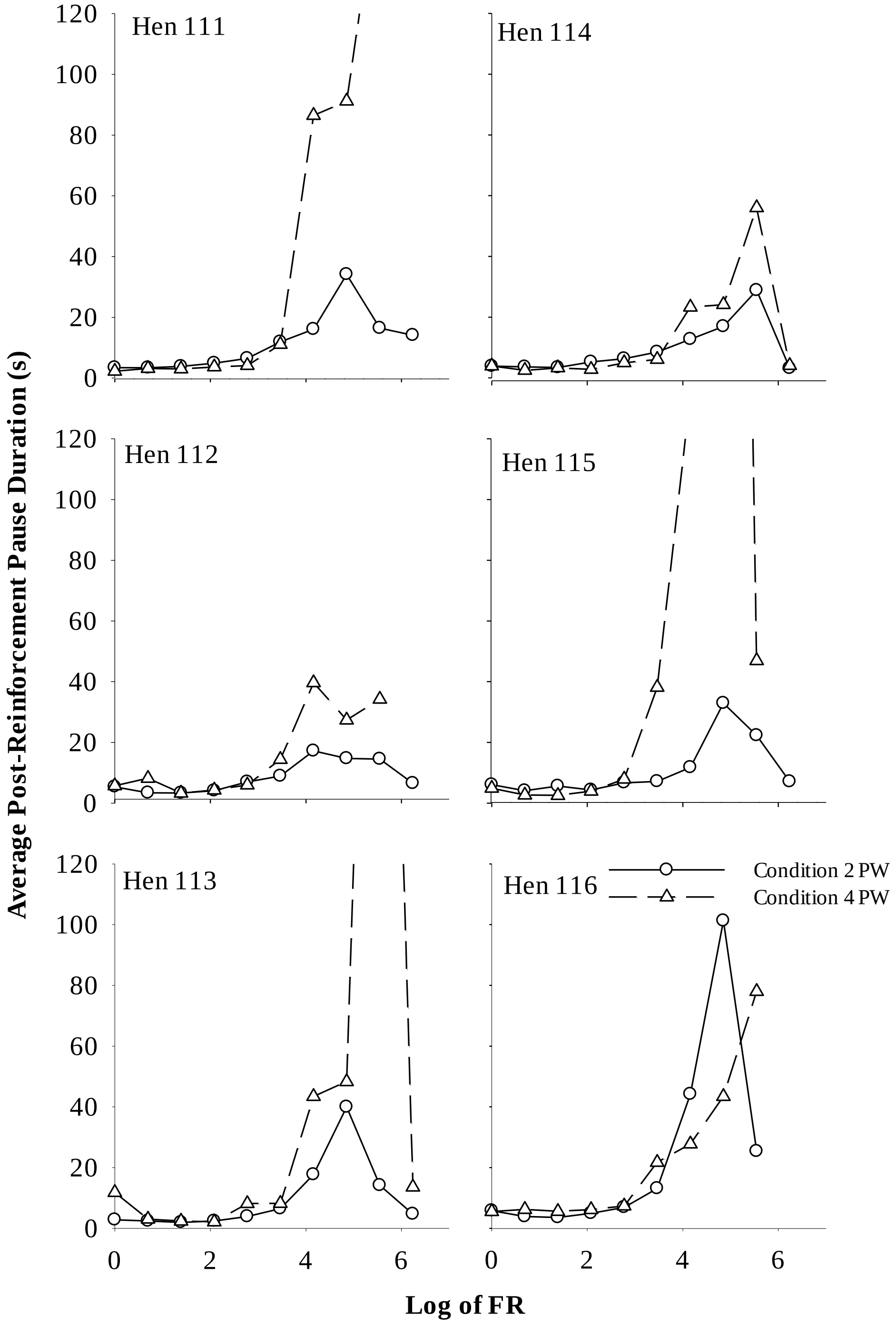

Figure 16. This graph shows the average PRP duration for FR schedules for each hen for Conditions 2 and 4.

Similarly, this was seen in the comparison between Conditions 3 and 4 (Figure 20). Examining the differences between Conditions 1 and 3 (Figure 19), where the body weight criteria was the independent variable, it is shown that there were no consistent differences between the amounts of wheat reinforcers obtained. Again, this was also true for Conditions 2 and 4, as seen in Figure 21.

Consumption can also be measured in the weight (g) of food consumed. Figure 22 shows the natural logarithm of the amount eaten (weight of the food consumed in grams) plotted against the logarithm of the FR value for each condition. These figures show curvilinear demand. There were no consistent differences across the two series in Condition 1 (far-left column). There are also no differences seen in the two series in Condition 2 (middle-left column). Condition 3 also showed no differences for the two hens that completed two series, as shown in the middle-right column of Figure 22.

As there were no consistent differences, the averages of each condition were then compared, against those of other conditions, in Figures 23 - 26. The comparison between Conditions 1 and 2 showed that when the amount eaten was plotted, the function was similar in shape however the amount of W eaten was higher than PW in all hens (Figure 23). Furthermore, this was also seen in Figure 25, where more wheat by weight (Condition 3) was consumed over puffed wheat (Condition 4). Examining the differences between Conditions 1 and 3, where the control of body weight was the independent variable, it is shown that there was no consistent difference between the amount eaten (Figure 24), the lines fall almost directly on top of one another for all six hens. Again, this is seen when Conditions 2 and 4 shown in Figure 26.

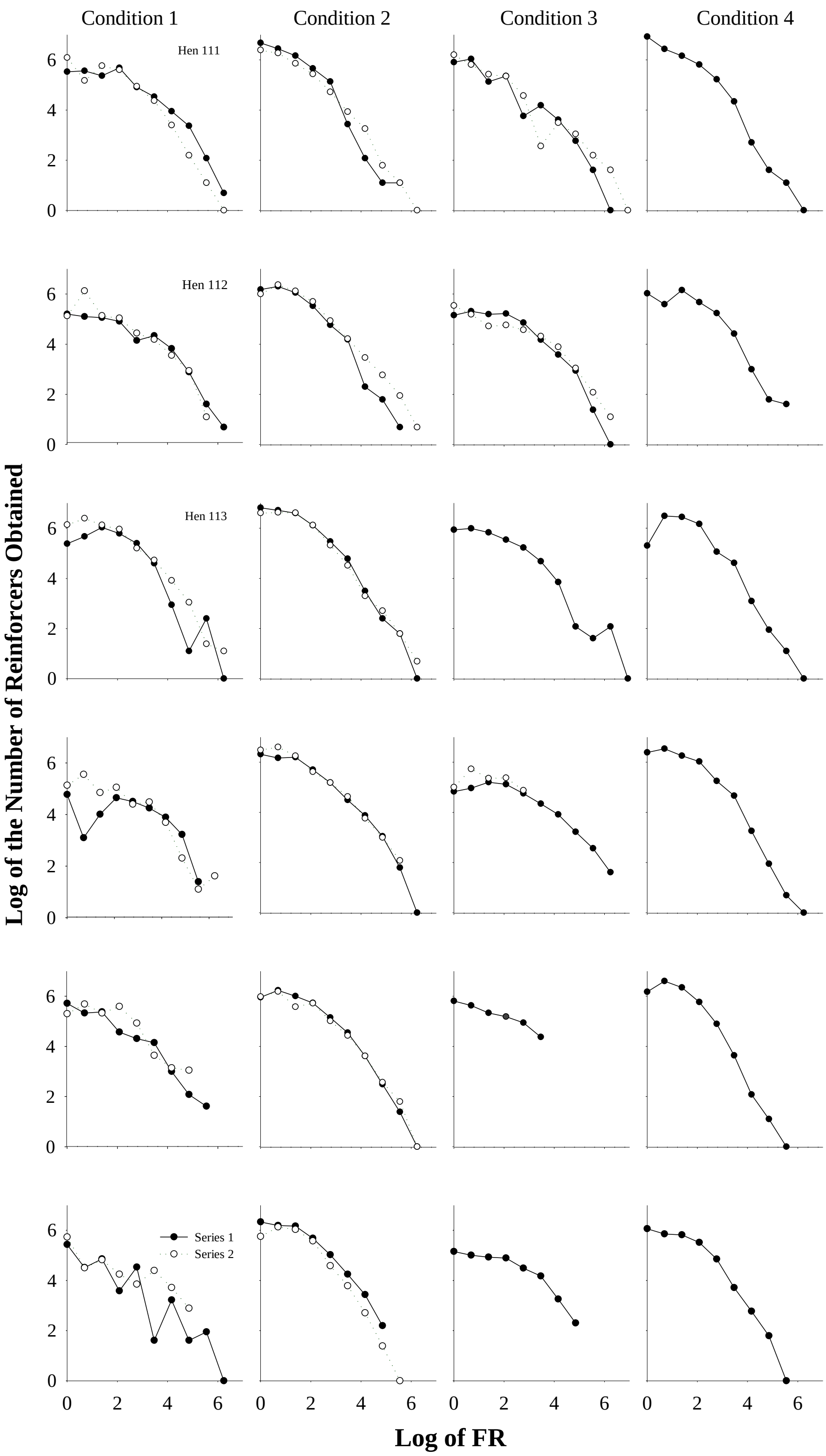

Figure 17. This graph shows the log of the number of reinforcers obtained at each FR schedule for each hen across all four conditions.

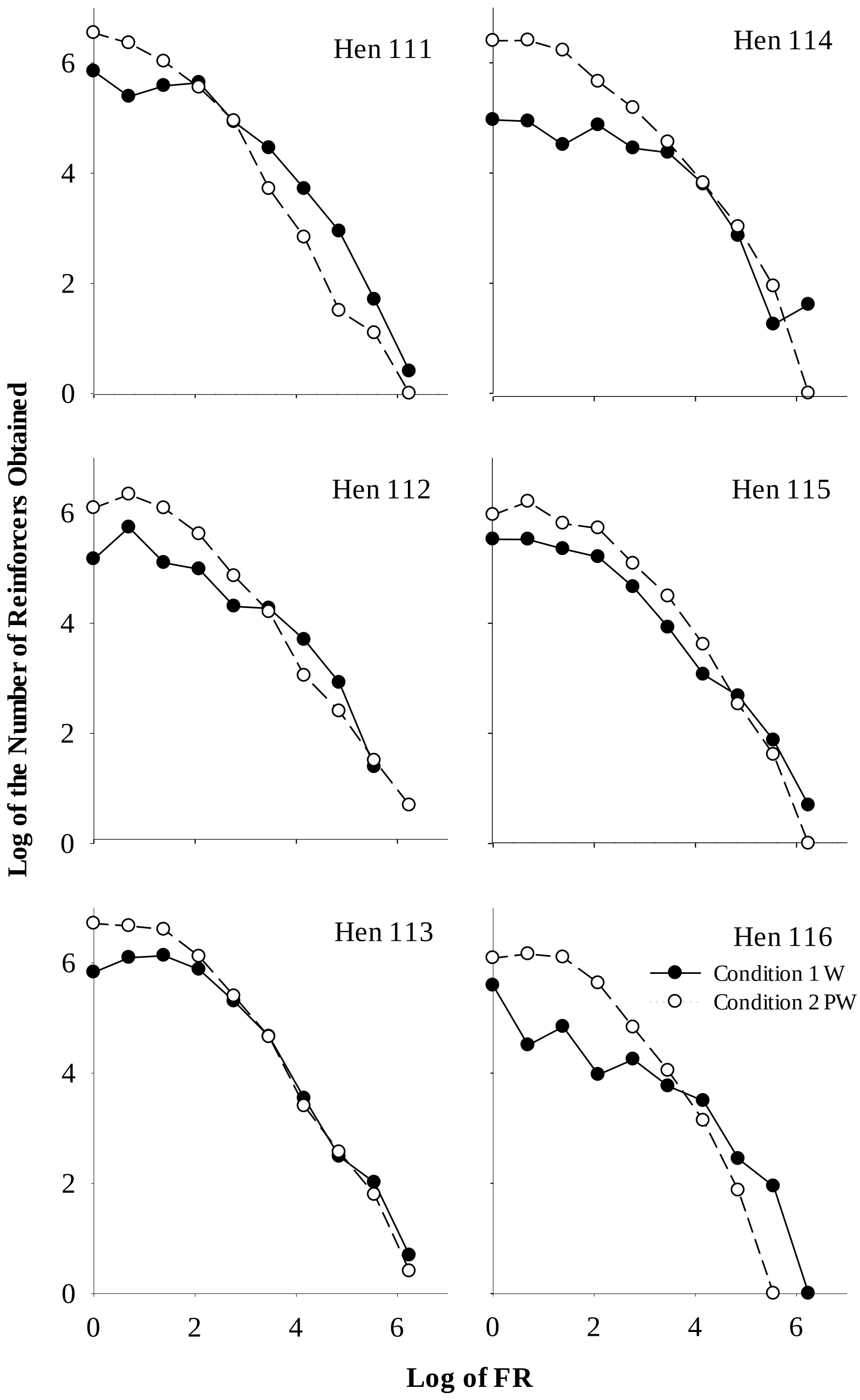

Figure 18. This graph shows the log of the number of reinforcers obtained at each FR schedule for each hen across.

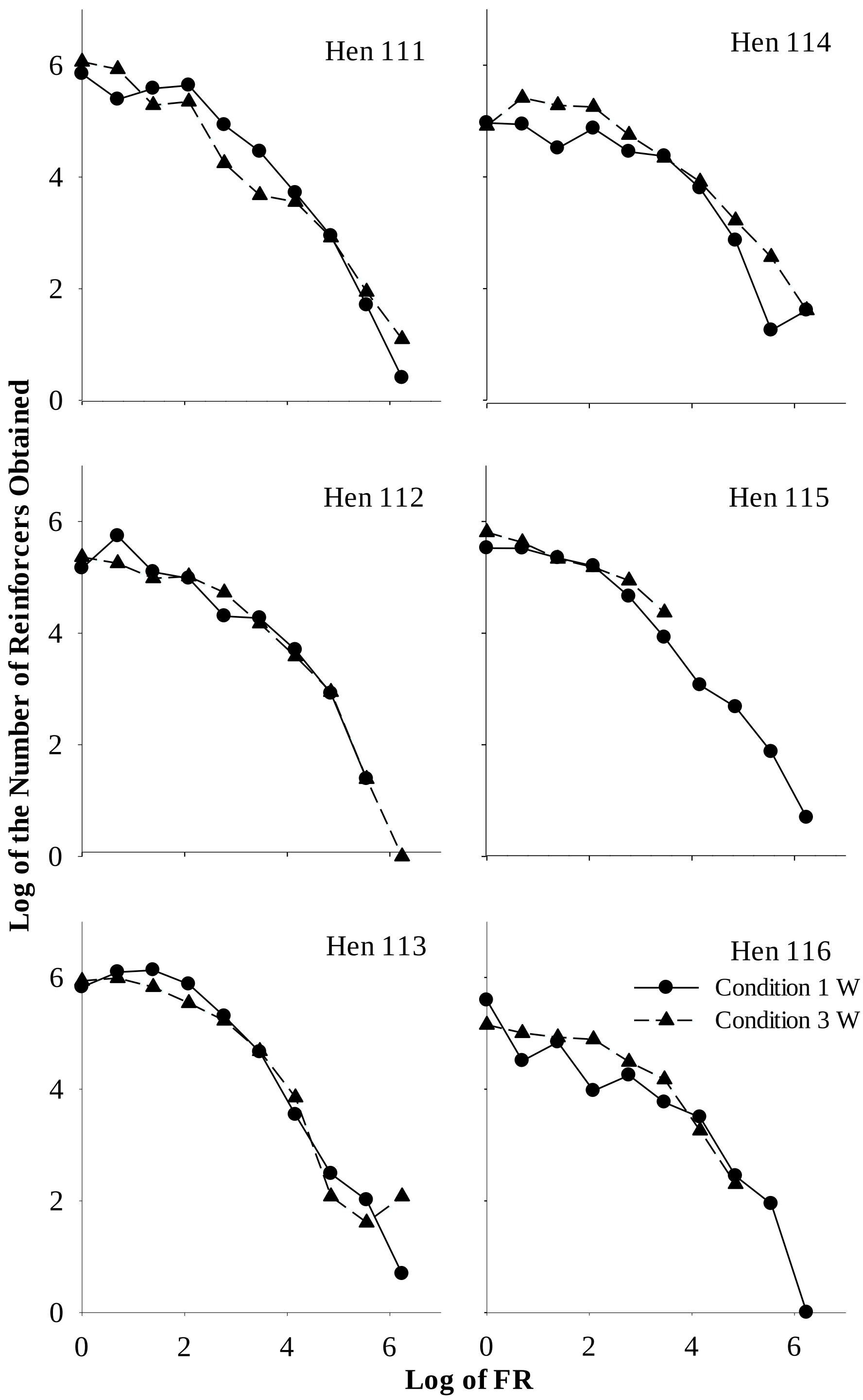

Figure 19. This graph shows the log of the number of reinforcers obtained at each FR schedule for each hen across Conditions 1 and 3.

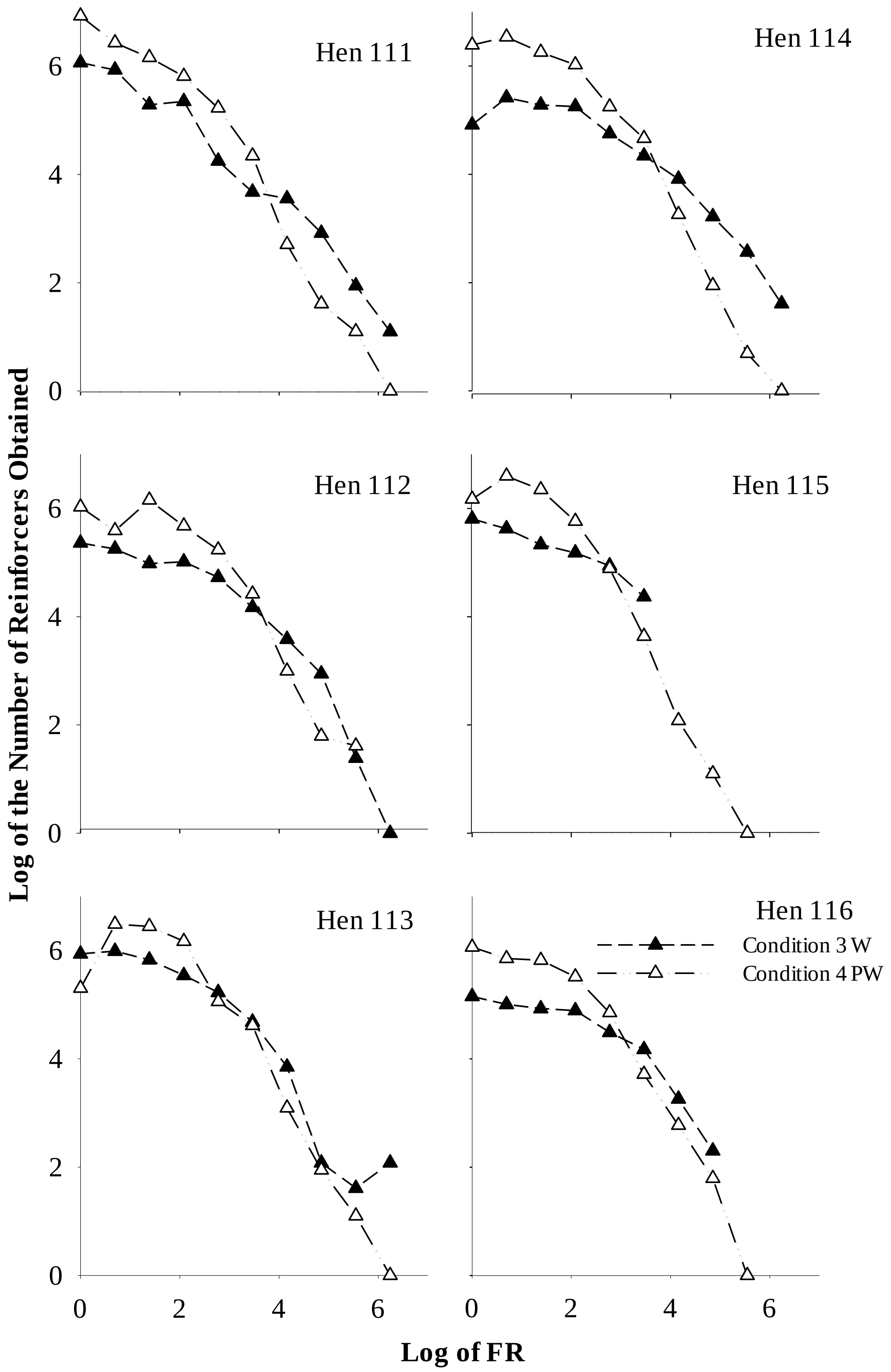

Figure 20. This graph shows the log of the number of reinforcers obtained at each FR schedule for each hen across Conditions 3 and 4.

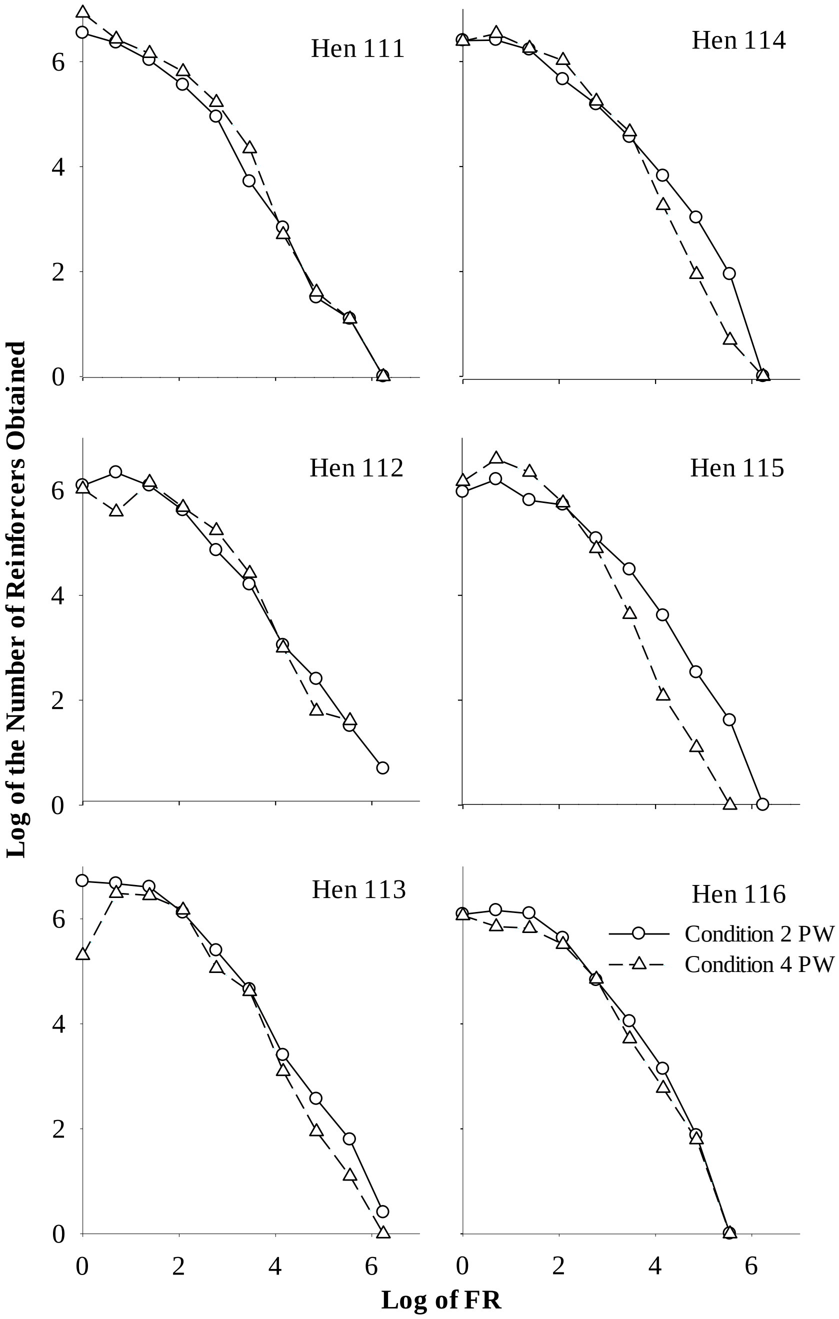

Figure 21. This graph shows the log of the number of reinforcers obtained at each FR schedule for each hen across Conditions 2 and 4.

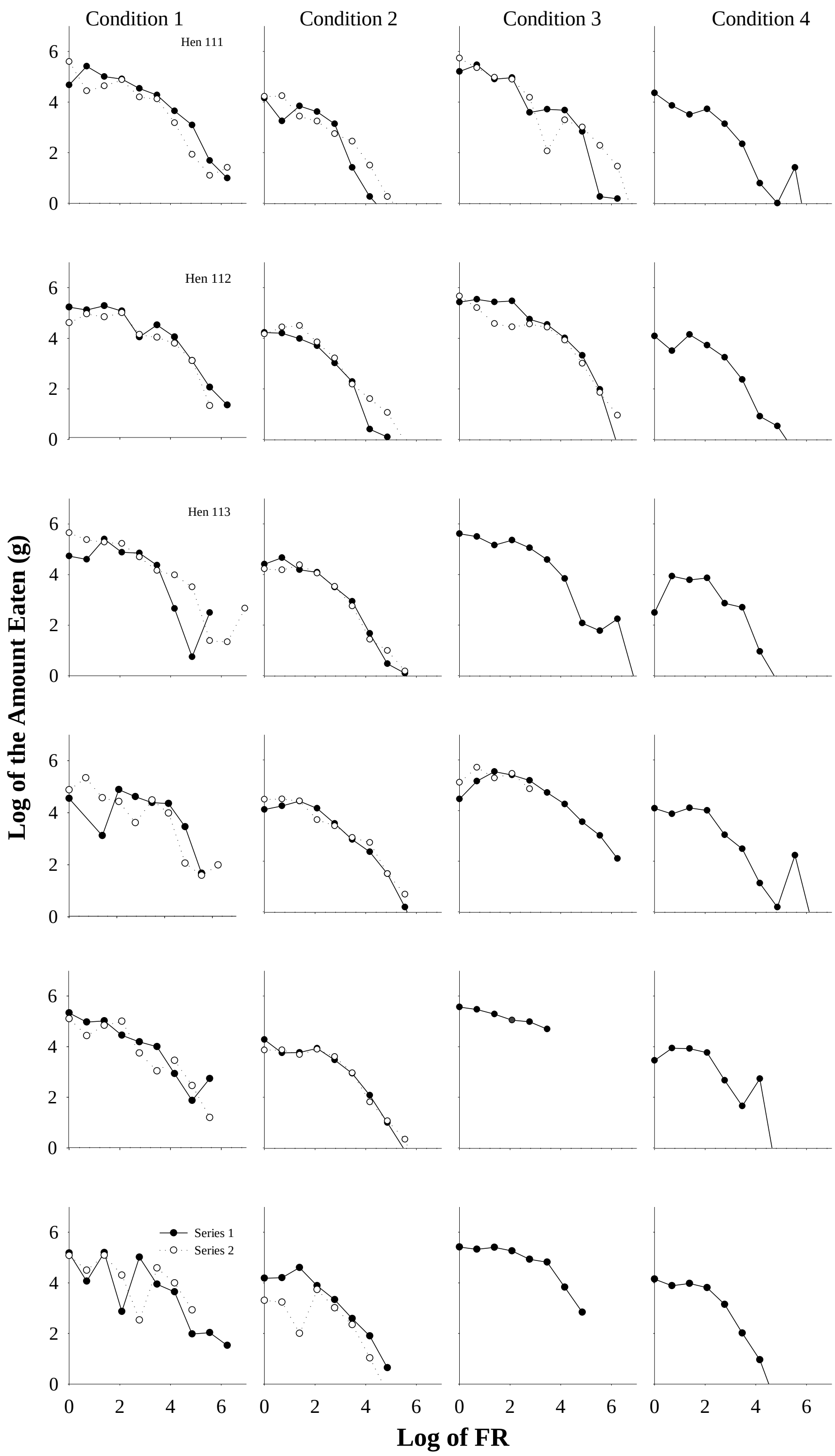

Figure 22. This graph shows the log of the weight of food consumed under each FR schedule for each hen across all four conditions.

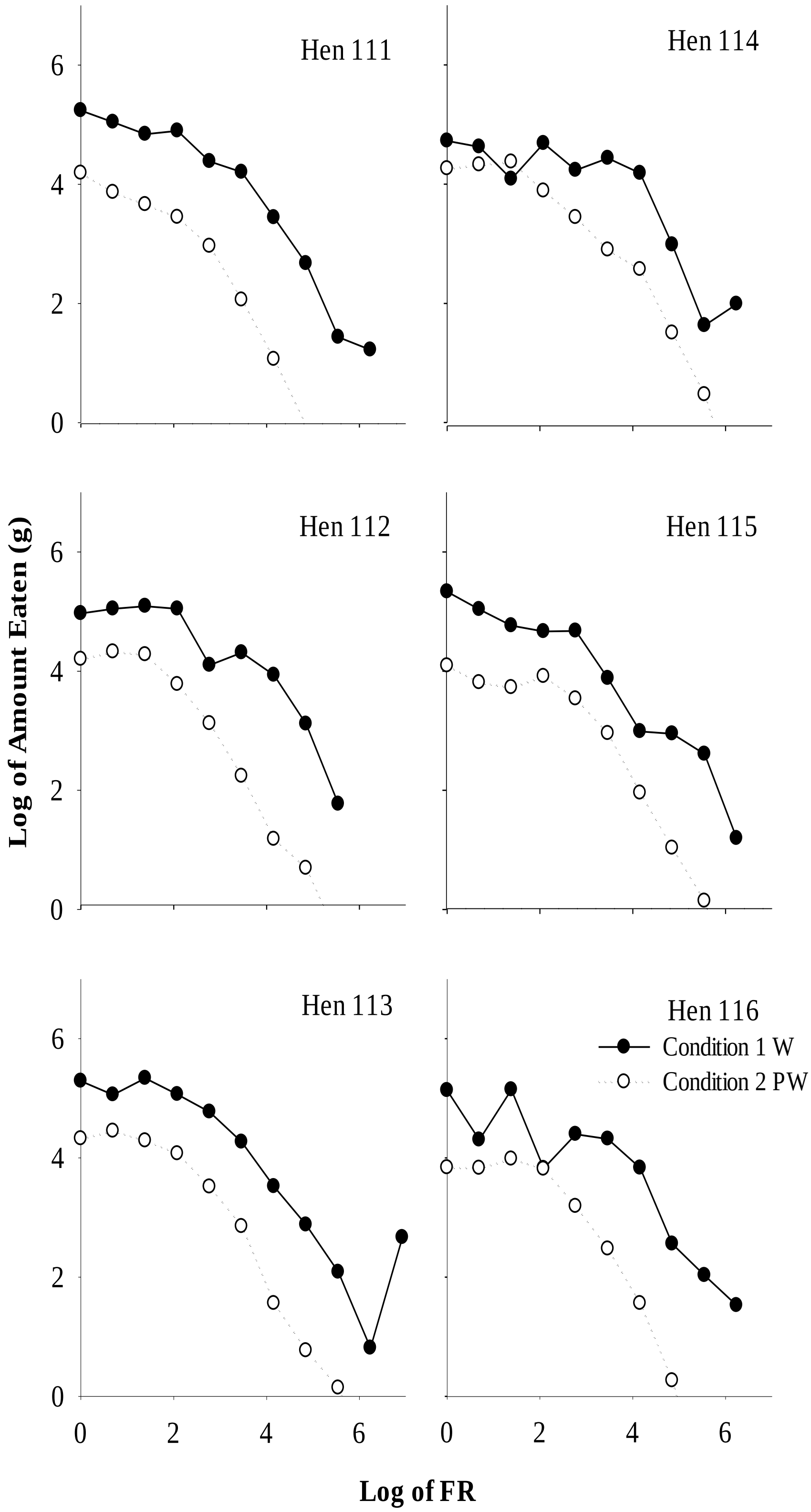

Figure 23. This graph shows the log of the weight of food consumed under each FR schedule for each hen across Conditions 1 and 2.

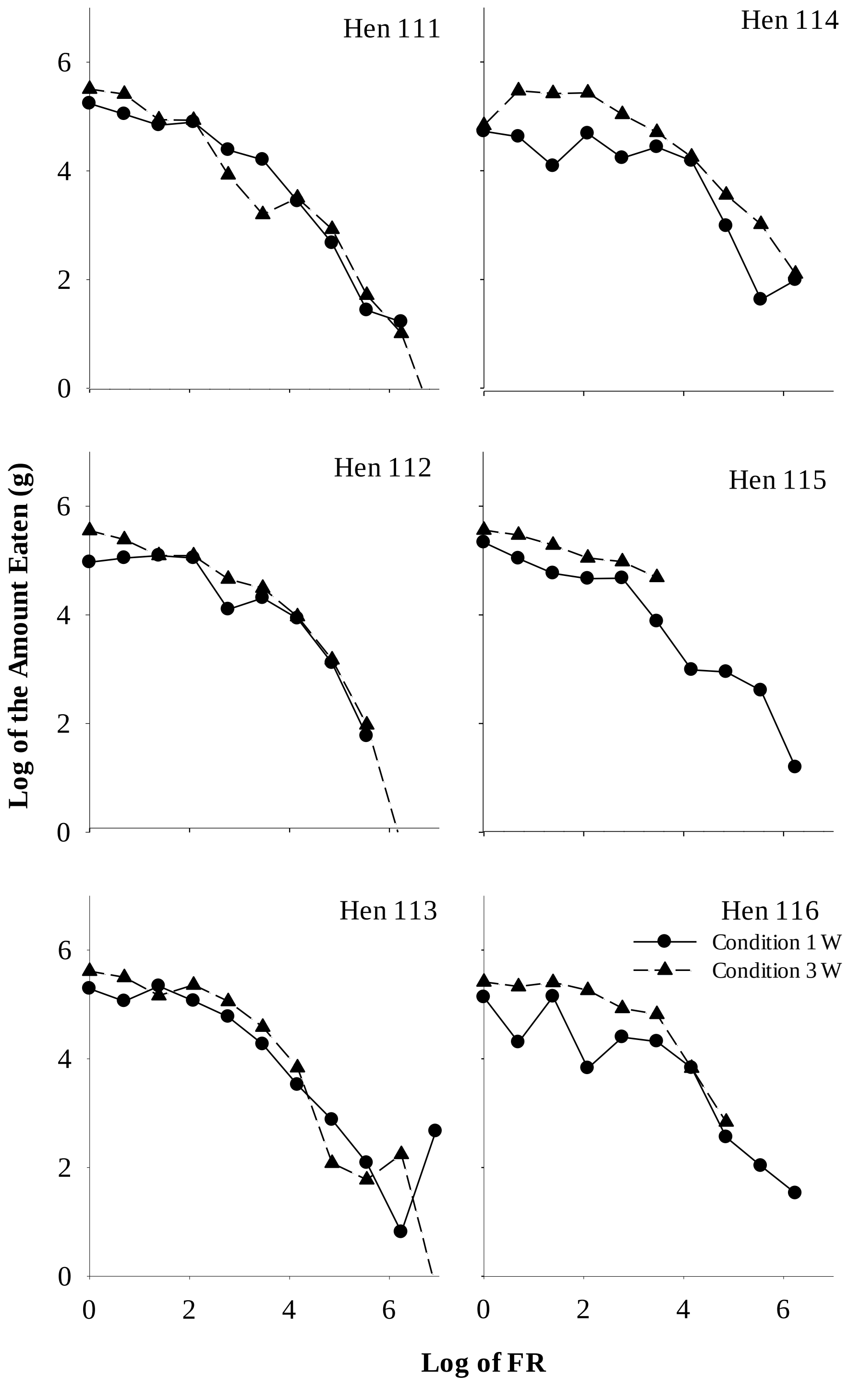

Figure 24. This graph shows the log of the weight of food consumed under each FR schedule for each hen across Conditions 1 and 3.

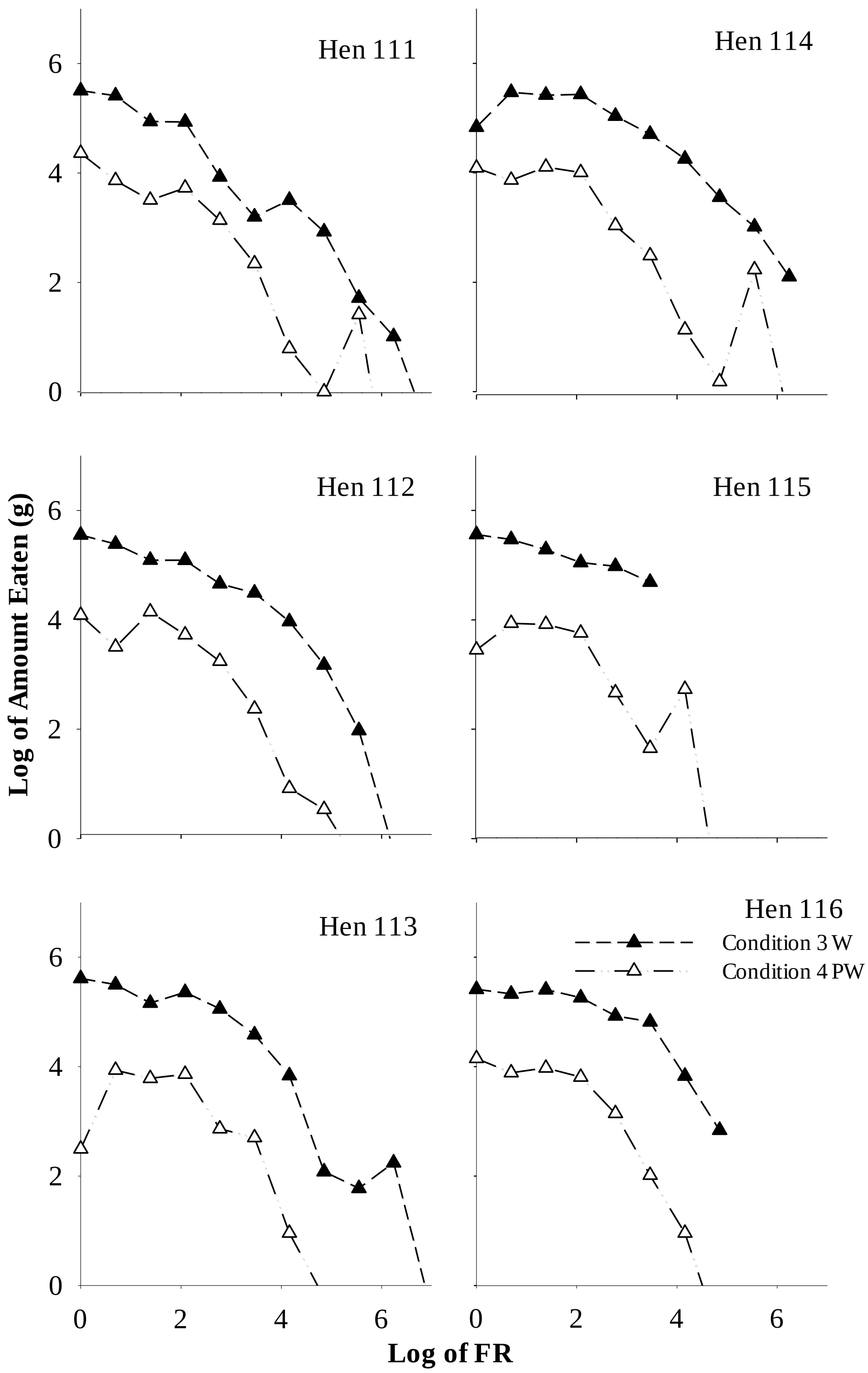

Figure 25. This graph shows the log of the weight of food consumed under each FR schedule for each hen across Conditions 3 and 4.

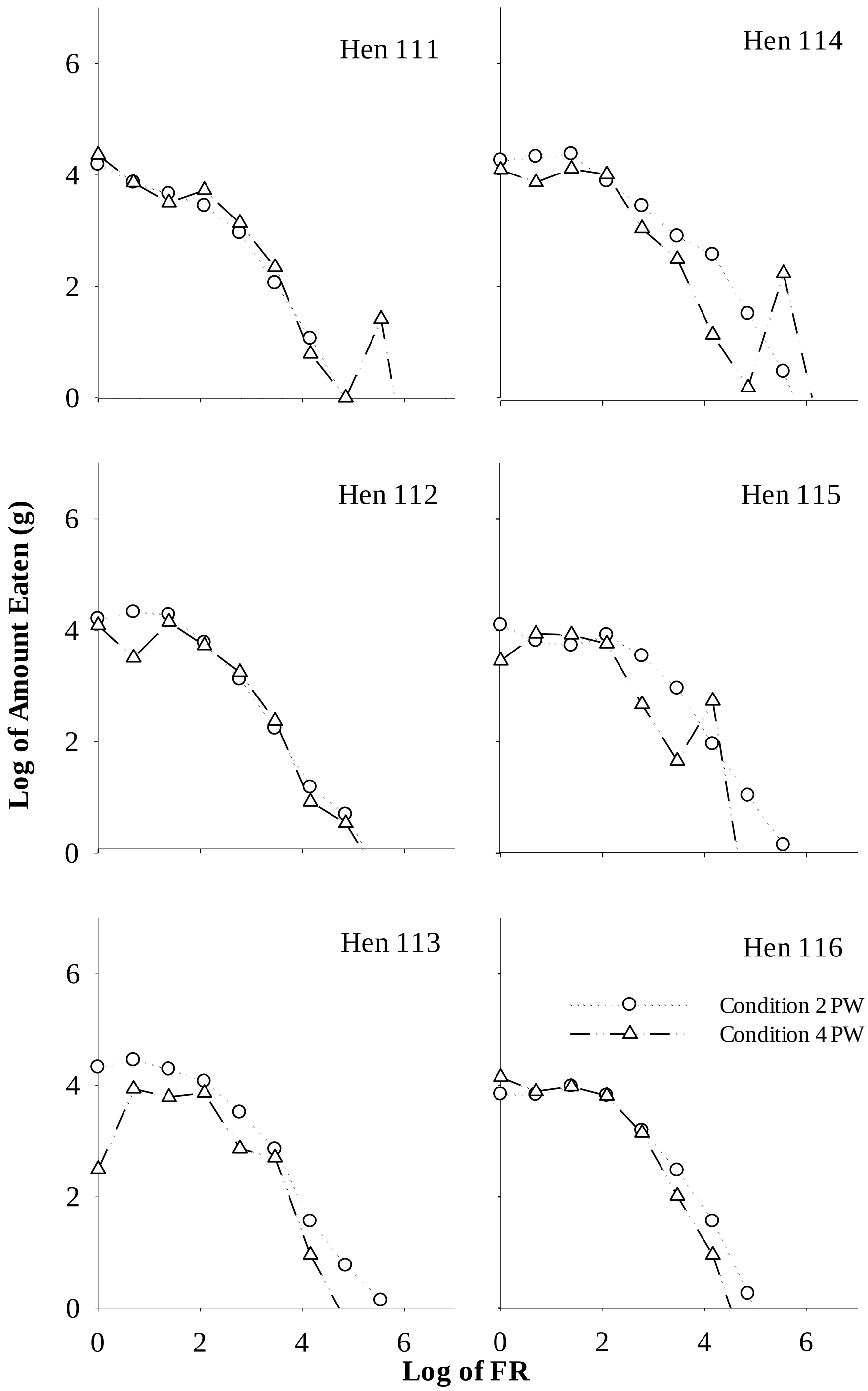

Figure 26. This graph shows the log of the weight of food consumed under each FR schedule for each hen across Conditions 2 and 4.

Hursh et al.'s (1988) non-linear equation (Equation 1) was fitted to the data presented in the demand graphs. The parameters ln *L*, *b* and *a* were calculated for the average data for each condition, and are presented in the following tables. Table 2 presents the parameter values ln *L*, *b* and *a* for each hen under all four conditions, using the reinforcers obtained as the consumption measure. The parameter ln *L* is the initial consumption, where price is at its lowest point (FR1). The initial elasticity is represented by *b* and the parameter *a* shows the deceleration of the slope as the price increases (Hursh et al., 1988). The parameter ln *L* was generally higher in the PW conditions compared to the W conditions. The parameter *b* was generally lower for the PW conditions compared to the W conditions. There were no consistent differences between the *a* values across the conditions. The variance accounted for by the lines fitted using the equation (*%VAC*), the residual standard error of the estimates (*RSE*) and the P_{max} values, the price associated with the maximum response output (calculated using Equation 2), are also shown in Table 2. In Table 2, the P_{max} values were generally higher for the W conditions (1 and 3) compared to the PW conditions. The *RSE* and *%VAC* values in Table 2 show that the function described the data well.

Table 3 presents the parameter values for all hens, for all four conditions, using the amount eaten (in grams) as the consumption measure. The parameter ln *L* was lower in the PW conditions compared to the W conditions. There were no consistent differences in the *a* or *b* parameter values across the four conditions. The P_{max} values were higher in the W than the PW conditions. Again, the *RSE* and the *%VAC* show that the function fits the data well.

Table 2. This table shows the parameters ln *L*, *b* and *a* when Hursh et al.'s (1988) equation (Equation 1) fitted to the ln consumption of reinforcement (shown in Figure 17*). %VAC, RSE* and P_{max} (calculated by Equation 2) also shown.

	Condition		ln *L*	*b*	*a*	*RSE*	*%VAC*	P_{max}
Hen 111	1	W	6.06	-0.44	0.0061	0.33	97.53	91.65
	2	PW	7.10	-0.96	0.0026	0.44	97.41	16.97
	3	W	6.30	-0.68	0.0016	0.24	98.84	195.51
	4	PW	7.37	-0.97	0.0030	0.50	96.86	9.24
Hen 112	1	W	5.51	-0.28	0.0101	0.26	97.22	71.66
	2	PW	6.79	-0.77	0.0029	0.42	96.73	78.12
	3	W	5.55	-0.35	0.0056	0.23	98.40	115.75
	4	PW	6.45	-0.57	0.0083	0.63	90.92	51.42
Hen 113	1	W	6.74	-0.71	0.0021	0.58	94.75	136.22
	2	PW	7.30	-0.78	0.0043	0.42	97.39	51.26
	3	W	6.57	-0.68	0.0018	0.63	92.86	181.21
	4	PW	6.70	-0.67	0.0057	0.82	90.44	57.81
Hen 114	1	W	5.24	-0.35	0.0039	0.54	88.07	168.91
	2	PW	6.76	-0.57	0.0063	0.20	99.30	67.47
	3	W	5.49	-0.29	0.0044	0.33	94.98	162.80
	4	PW	7.16	-0.82	0.0049	0.60	95.39	36.86
Hen 115	1	W	5.93	-0.54	0.0038	0.30	97.58	120.05
	2	PW	6.51	-0.57	0.0061	0.35	97.85	70.13
	3	W	5.81	-0.22	0.0199	0.07	98.96	39.12
	4	PW	7.07	-0.88	0.0099	0.64	95.03	12.16
Hen 116	1	W	5.21	-0.37	0.0055	0.32	96.98	114.35
	2	PW	6.54	-0.55	0.0142	0.31	98.46	31.75
	3	W	5.20	-0.15	0.0175	0.12	98.99	48.50
	4	PW	6.41	-0.59	0.0127	0.34	98.09	31.90

Table 3. This table shows the parameters ln *L*, *b* and *a* when Hursh et al.'s (1988) equation (Equation 1) fitted to the ln consumption of reinforcement (shown in Figure 22). *%VAC*, *RSE* and P_{max} (calculated by Equation 2) also shown.

	Condition		**ln *L***	***b***	***a***	***RSE***	***%VAC***	***Pmax***
Hen 111	1	W	5.50	-0.45	0.0036	0.38	95.05	154.23
	2	PW	4.54	-0.71	0.0050	0.36	97.97	58.30
	3	W	5.70	-0.56	0.0025	0.30	98.19	178.92
	4	PW	4.45	-0.59	0.0051	0.82	88.13	80.25
Hen 112	1	W	5.14	-0.16	0.0098	0.25	96.26	85.99
	2	PW	4.95	-0.81	0.0012	0.53	94.12	156.57
	3	W	5.58	-0.27	0.0082	0.08	99.85	89.98
	4	PW	4.38	-0.52	0.0089	0.53	92.85	54.61
Hen 113	1	W	5.95	-0.65	-0.0005	0.72	82.09	-776.47
	2	PW	4.94	-0.65	0.0042	0.46	95.94	83.75
	3	W	6.02	-0.54	0.0023	0.63	91.76	197.89
	4	PW	3.89	-0.45	0.0072	0.86	87.56	76.37
Hen 114	1	W	4.83	-0.22	0.0038	0.55	81.82	203.49
	2	PW	4.64	-0.42	0.0065	0.24	98.68	88.82
	3	W	5.46	-0.20	0.0045	0.36	92.29	177.97
	4	PW	4.53	-0.61	0.0017	0.88	78.97	233.44
Hen 115	1	W	5.41	-0.41	0.0031	0.29	96.30	190.88
	2	PW	4.32	-0.39	0.0077	0.34	97.76	79.64
	3	W	5.58	-0.21	0.0053	0.05	98.32	150.81
	4	PW	4.13	-0.43	0.0126	0.98	81.89	45.12
Hen 116	1	W	5.05	-0.32	0.0035	0.50	87.81	195.58
	2	PW	4.19	-0.32	0.0164	0.31	98.07	41.37
	3	W	5.46	-0.05	0.0190	0.13	98.53	49.86
	4	PW	4.54	-0.56	0.0160	0.49	96.82	27.42

Data was also analysed using Hursh and Silberberg (2008)'s equation (Equation 3). The parameters Q_0, k and α were calculated are presented in the following tables. The parameter Q_0 presents an approximation of the highest amount of consumption when price is at the lowest point, i.e. FR 1. The parameter k gives the range of consumption. The parameter α indicates the change in consumption as the cost increases. As k is the scaling parameter, and kept constant across conditions, changes in α can be observed.

Table 4 presents these parameters, Q_0, k and α, for the number of reinforcers obtained for each hen, when k calculated using the maximum range of consumption. The residual standard error of the estimates (*RSE*) and P_{max}, and P_{max} normalised are also presented. The parameter Q_0, was higher in the PW conditions (2 and 4) than the W conditions.

Table 5 presents the same parameters when k was calculated using the average range of consumption, using reinforcers obtained as the consumption measure. In both tables (4 and 5), the parameter Q_0, was higher in the PW conditions (2 and 4). A decrease was observed between Conditions 1 and 2 in alpha (α) across the different food types; however, this difference was not seen in Conditions 3 and 4. Instead, α increased for the PW condition. Hen 115 did not generate a P_{max} value, however, these were generally higher in the W conditions (1 and 3) compared to the PW conditions.

Furthermore, Hursh and Silberberg's (2008) equation was fitted to the amount eaten data. Tables 6 and 7 present the same parameter values using the amount eaten as the consumption measure, with the k calculated by the maximum and average range of consumption, respectively. The residual standard error of the estimates (*RSE*) and P_{max}, and P_{max} normalised are also presented. Using the weight of food eaten as the consumption measure, both tables show that the parameter Q_0 was higher in the W conditions compared to the PW conditions. Alpha (α) was consistently higher in the PW conditions (2 and 4) compared to the W conditions (1 and 3). The P_{max}, and P_{max} normalised values were also higher for W compared to PW.

Weights

The daily weights of hens were also recorded. Figure 27 and 28 show the weight (in grams) for each hen across the experimental conditions. The weights are shown from the start of the series, until the last FR value at which the hen terminated the series. There is a break in the data recordings between 26 December 2013 and 6 January 2014, due to an equipment malfunction, meaning no data was recorded during this time. Following this, Condition 3 resumed. The individualized target weights for each hen are shown which were calculated as 80 ± 5% of their free-feeding weight, and are indicated by the horizontal lines.

Figures 27 and 28 show that the weights were more variable in the W conditions (Conditions 1 and 3), compared to those seen in the PW conditions. Hens rarely fell outside of target range while responding for PW, especially in Condition 4, which had strict body weight control periods, and therefore show little difference when compared to Condition 2.

Table 4. The table shows the parameters Q_0, k and α calculated when Hursh and Silberberg's (2008) equation (Equation 3) was fitted to the number of reinforcers, when k was calculated by the maximum range of consumption. The table also includes the residual standard error of the estimates (*RSE*) and P_{max}, and P_{max} normalised are also presented.

	Condition		Q_0	α	k	RSE	Pmax	Pmax[Normalised]
Hen 111	1	W	225.91	0.000010	3.51	0.95	63.85	144.24
	2	PW	495.74	0.000012	3.51	0.88	25.46	126.20
	3	W	150.05	0.000009	3.51	0.84	110.13	165.25
	4	PW	835.47	0.000009	3.51	0.91	18.82	157.23
Hen 112	1	W	171.96	0.000017	3.25	0.95	55.58	95.58
	2	PW	328.09	0.000011	3.25	0.87	42.80	140.44
	3	W	151.99	0.000013	3.25	0.96	78.75	119.69
	4	PW	347.08	0.000014	3.25	0.90	32.19	111.73
Hen 113	1	W	323.13	0.000008	3.42	0.89	62.19	200.95
	2	PW	588.98	0.000007	3.42	0.91	35.46	208.86
	3	W	215.39	0.000007	3.42	0.82	95.99	206.74
	4	PW	445.35	0.000011	3.42	0.92	31.46	140.10
Hen 114	1	W	107.87	0.000014	3.34	0.85	105.66	113.97
	2	PW	394.75	0.000009	3.34	0.96	45.89	181.15
	3	W	148.24	0.000009	3.34	0.92	113.90	168.84
	4	PW	701.39	0.000010	3.34	0.97	21.86	153.33
Hen 115	1	W	156.19	0.000013	3.37	0.89	74.26	115.98
	2	PW	323.44	0.000011	3.37	0.96	45.26	146.39
	3	W	5.71	0.000000	3.37	0.06		
	4	PW	757.84	0.000016	3.37	0.97	12.52	94.87
Hen 116	1	W	99.67	0.000020	3.18	0.92	79.96	79.70
	2	PW	428.90	0.000017	3.18	0.98	21.86	93.74
	3	W	156.87	0.000025	3.18	0.99	41.61	65.28
	4	PW	361.40	0.000021	3.18	0.98	22.00	79.49

Table 5. The table shows the parameters Q_0, k and α calculated when Hursh and Silberberg's (2008) equation (Equation 3) was fitted to the number of reinforcers, when k was calculated by the average range of consumption. The table also includes the residual standard error of the estimates (*RSE*) and P_{max}, and P_{max} normalised are also presented.

	Condition		Q_0	α	*k*	*RSE*	*Pmax*	*Pmax*[Normalised]
Hen 111	1	W	356.89	0.000012	2.96	0.95	41.89	149.50
	2	PW	754.10	0.000017	2.96	0.96	13.45	101.42
	3	W	184.23	0.000012	2.96	0.88	78.46	144.54
	4	PW	898.88	0.000015	2.96	0.98	13.42	120.60
Hen 112	1	W	176.77	0.000021	2.76	0.95	51.73	91.44
	2	PW	531.92	0.000016	2.76	0.94	22.34	118.81
	3	W	161.53	0.000017	2.76	0.98	68.93	111.35
	4	PW	427.96	0.000019	2.76	0.93	23.98	102.61
Hen 113	1	W	323.13	0.000011	2.95	0.94	48.32	48.32
	2	PW	588.98	0.000010	2.95	0.95	28.59	168.41
	3	W	215.39	0.000010	2.95	0.85	78.12	168.27
	4	PW	539.37	0.000015	2.95	0.96	22.34	120.48
Hen 114	1	W	115.72	0.000018	2.73	0.87	91.13	105.46
	2	PW	442.98	0.000012	2.73	0.97	35.20	155.93
	3	W	154.73	0.000012	2.73	0.93	102.36	158.39
	4	PW	640.95	0.000016	2.73	0.98	18.27	117.07
Hen 115	1	W	184.46	0.000019	2.66	0.92	55.29	101.99
	2	PW	382.81	0.000016	2.66	0.98	31.71	121.40
	3	W	5.71	0.000000	2.66	0.06		
	4	PW	685.47	0.000028	2.66	0.99	10.29	70.57
Hen 116	1	W	104.18	0.000026	2.69	0.93	71.60	74.59
	2	PW	452.97	0.000023	2.69	0.99	18.41	83.41
	3	W	159.24	0.000031	2.69	0.99	40.04	63.77
	4	PW	396.89	0.000028	2.69	0.99	17.81	70.70

Table 6. The table shows the parameters Q_0, k and α calculated when Hursh and Silberberg's (2008) equation (Equation 3) was fitted to weight of food consumed, when k was calculated by the maximum range of consumption. The table also includes the residual standard error of the estimates (*RSE*) and P_{max}, and P_{max} normalised are also presented.

	Condition		Q_0	α	k	RSE	Pmax	Pmax[Normalised]
Hen 111	1	W	116.74	0.000014	3.39	0.88	92.65	108.16
	2	PW	38.92	0.000101	3.39	0.94	38.91	15.14
	3	W	111.46	0.000015	3.39	0.82	94.58	105.41
	4	PW	32.89	0.000078	3.39	0.81	59.44	19.55
Hen 112	1	W	132.05	0.000016	3.01	0.96	84.12	111.08
	2	PW	58.63	0.000078	3.01	0.84	37.78	22.15
	3	W	189.21	0.000015	3.01	0.99	61.51	116.39
	4	PW	46.50	0.000111	3.01	0.92	33.35	15.51
Hen 113	1	W	132.91	0.000006	3.21	0.52	194.15	258.04
	2	PW	60.80	0.000057	3.21	0.91	46.54	28.30
	3	W	156.70	0.000009	3.21	0.84	109.32	171.31
	4	PW	32.34	0.000119	3.21	0.92	41.90	13.55
Hen 114	1	W	89.02	0.000015	2.92	0.82	136.60	121.59
	2	PW	60.22	0.000056	2.92	0.97	52.96	31.89
	3	W	172.83	0.000008	2.92	0.92	128.42	221.95
	4	PW	32.03	0.000061	2.92	0.64	90.63	29.02
Hen 115	1	W	107.50	0.000014	3.10	0.85	111.26	119.60
	2	PW	47.77	0.000071	3.10	0.98	49.30	23.55
	3	W	232.67	0.000017	3.10	0.87	43.35	100.86
	4	PW	43.84	0.000134	3.10	0.86	28.52	12.50
Hen 116	1	W	90.17	0.000014	3.30	0.83	125.84	113.48
	2	PW	50.95	0.000105	3.30	0.99	29.40	14.98
	3	W	228.93	0.000015	3.30	0.99	47.03	107.67
	4	PW	64.50	0.000133	3.30	1.00	18.30	11.80

Table 7. The table shows the parameters Q_0, k and α calculated when Hursh and Silberberg's (2008) equation (Equation 3) was fitted to weight of food consumed, when k was calculated by the maximum range of consumption. The table also includes the residual standard error of the estimates (*RSE*) and P_{max}, and P_{max} normalised are also presented.

	Condition		Q_0	α	k	RSE	Pmax	Pmax[Normalised]
Hen 111	1	W	125.39	0.000018	2.87	0.90	80.17	100.52
	2	PW	49.09	0.000140	2.87	0.97	26.56	13.04
	3	W	118.41	0.000019	2.87	0.84	83.05	98.34
	4	PW	36.77	0.000103	2.87	0.82	48.15	17.71
Hen 112	1	W	141.26	0.000022	2.41	0.97	72.18	101.96
	2	PW	101.41	0.000141	2.41	0.96	15.73	15.95
	3	W	192.35	0.000021	2.41	0.98	54.59	105.01
	4	PW	58.68	0.000165	2.41	0.96	23.24	13.64
Hen 113	1	W	132.91	0.000009	2.72	0.56	166.60	221.42
	2	PW	82.23	0.000079	2.72	0.95	29.75	24.46
	3	W	190.53	0.000013	2.72	0.87	78.17	148.93
	4	PW	37.26	0.000164	2.72	0.94	31.67	11.80
Hen 114	1	W	92.69	0.000019	2.41	0.84	125.57	116.38
	2	PW	64.13	0.000079	2.41	0.98	44.08	28.27
	3	W	178.81	0.000011	2.41	0.93	119.16	213.07
	4	PW	36.47	0.000085	2.41	0.66	72.20	26.34
Hen 115	1	W	112.25	0.000018	2.59	0.87	100.93	113.29
	2	PW	50.35	0.000098	2.59	0.98	41.55	20.92
	3	W	233.10	0.000020	2.59	0.87	43.71	101.90
	4	PW	48.23	0.000181	2.59	0.87	23.48	11.32
Hen 116	1	W	94.33	0.000019	2.65	0.84	112.84	106.45
	2	PW	54.09	0.000149	2.65	0.99	24.70	13.36
	3	W	231.94	0.000019	2.65	0.99	45.22	104.89
	4	PW	62.30	0.000204	2.65	0.99	15.67	9.76

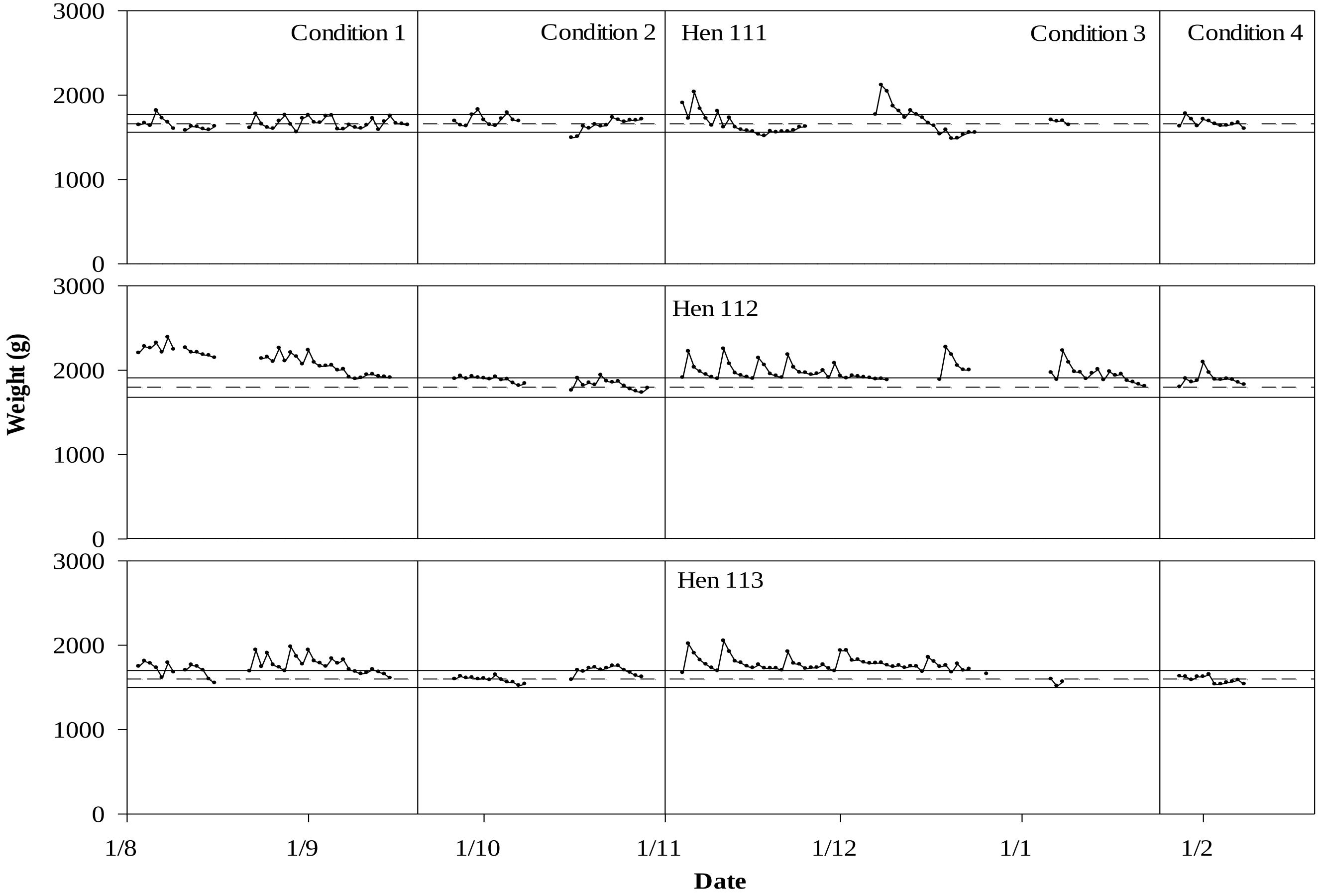

Figure 27. The daily body weights across Conditions 1 - 4 for hens 111, 112 and 113.

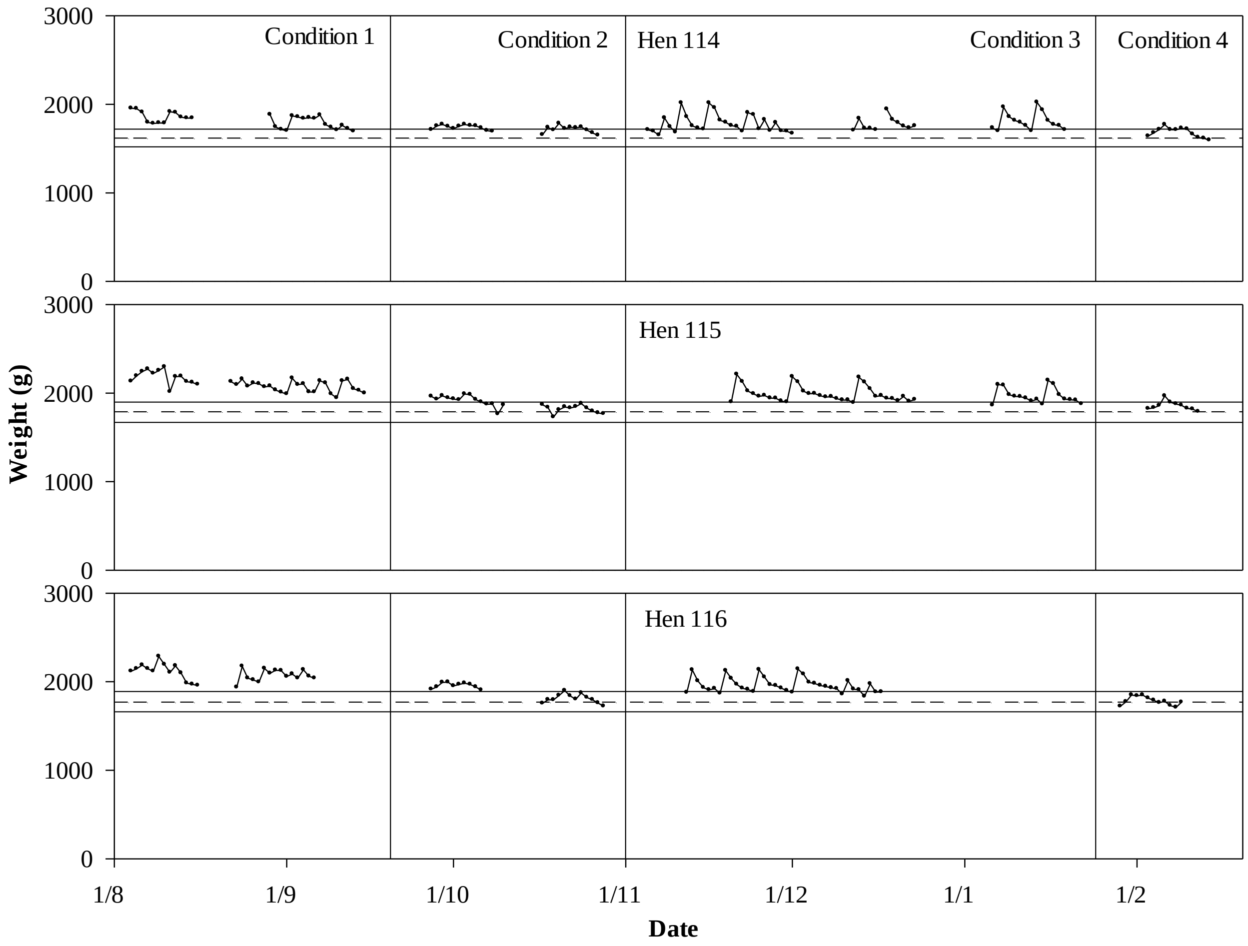

Figure 28. The daily body weights across Conditions 1 - 4 for hens 114, 115 and 116.

Discussion

One aim of this study was to examine the effects of different body weight criteria on performance, under FR schedules for two feeds, and the resulting demand functions. The first question is whether the different weight criteria resulted in different body weights. The weights recorded in the two PW conditions, 2 and 4, were very similar, with the hens being within the target range most days in both conditions. It is therefore expected that the results for these two PW conditions would be similar. The average difference in weight ranged from 1.6 – 11.2% above the 80 + 5% target weight in Condition 2. Hens had to meet the target criteria of being in the 80 ± 5% range in Condition 4. Weights differed more in the W conditions. In Condition 1, where there were relaxed body weight criteria, the hens were often above the target during the FR series, especially at low FR values. For Condition 1, the average body weights were between 2.5 – 28.3% higher than the 80 + 5% target criteria. In Condition 3, the increase in body weight after a session meant that there could be 2 - 10 days between sessions for some hens, at low FR values. The data also shows that there was a tendency for the hens to be at a higher body weight in Condition 1 (W), than in Condition 2 (PW).

If body weight had an effect on FR behaviour or demand, differences would be expected between Conditions 1 and 3 (both W), but not between Conditions 2 and 4 (both PW). Given that the difference between body weights was largest at low FR values, in Conditions 1 and 3, it might be expected that if body weight had an effect on performance or demand, the differences would be at low FR values, between the two W conditions.

Breakpoints

One variable that can be compared across the conditions is breakpoints. In most series, hens tended to be within weight range when a series terminated. There were series in Condition 1 and 2 where this was not so, and thus breakpoints for hens that were over the target weight when a series ended could be compared to those series that were terminated within where the hen was within the target weight range. There were no consistent differences in breakpoints found for this comparison, nor were there differences in breakpoint between Conditions 1 and 3, or between Conditions 2 and 4.

The breakpoints themselves were consistent with previous research when hens responded on fixed ratio schedules (e.g. Foster et al., 2009; Jackson, 2011). The present breakpoints were slightly higher in the W conditions compared to the PW conditions. Similar to the present results, Jackson (2011) found slightly higher breakpoints in W conditions, compared to PW conditions, in four of five hens under FR schedules. Foster et al. (2009) also found higher breakpoints in W conditions compared to PW in three hens, but there was no difference in breakpoints between feeds for two hens. One hen had higher breakpoints in the PW condition (Foster et al., 2009). The findings from the present study are therefore consistent with previous results, with a tendency for breakpoints to be higher for W compared to PW.

Although the present study found no reliable or consistent differences across the breakpoints for W, when body weight criteria were changed, there are studies that have found an effect of body weight. For example, Hodos (1961) found a difference in breakpoints under different body weights with rats pressing a lever under progressive-ratio (PR) schedules. The first experiment used different concentrations and volumes of sweetened condensed milk and water. The second experiment regulated the amount of food consumed daily, so that the rats' body weights dropped to approximately 80% of their free feeding weight. Hodos (1961) then increased the rats' food rations, so that over a four - six week period, the rats returned to their normal weights whilst testing continued with the sweetened condensed milk, held at a constant concentration. Hodos (1961) found that the breakpoints were reliably influenced by both changes in body weight, and the magnitude of the reward.

In the present study, the body weight criteria did not alter the body weight to the same degree as in Hodos' (1961) study. Had there been a difference in the current results, it would have been between the two W conditions where weights were most different. However, the biggest differences in weight were evident at low FR values, rather than high FR values where the series terminated. This could reduce any effect of body weight on breakpoints.

Response rates

Performance measures related to demand were also measured. Under fixed-ratio schedules, changes in the overall response rates lead to changes in consumption. The present study found that overall response rates initially increased as the FR requirement increased, before peaking, and then decreasing. These patterns were consistent with the research Crossman et al. (1987) conducted. Foster et al. (1997) also found that as the ratio requirement increased, overall response rates decreased. Jackson (2011) found bitonic response rates in three of her five hens when they responded on FR schedules, a finding which is similar to the present data.

The current results showed that regardless of the body weight criterion, overall response rates were higher for PW than W at low FR values, but lower for PW than W at higher FR values. As in the present study, differences between the response rates for PW and W were found in Foster et al. (2009), who reported higher overall response rates in the less preferred food — HPW and PW compared to W — for FR values less than 64. Foster et al. (2009) concluded that the overall response rates reflected the longer PRPs which were observed for the more preferred reinforcer, W. This is interesting because although the overall response rates reflected those which Foster et al. (2009) found, the current results did not show corresponding increases in PRP in the W conditions, as discussed later.

Foster et al. (2009) noted that there was a relationship between lower response rates and the more preferred food, which was also found in this study. Preferences were assessed by Schroeder (2012), who examined the preferences for W, PW and pellets (P) for six hens, five of which were used in the current experiment. One condition in which the hens were fed P as the maintenance diet, and the preference was assessed between W and PW, was similar to the conditions in the current experiment. Schroeder (2012) found all that six hens had a strong preference for W over PW. Thus, for 111, 112, 114, 115 and 116, W was known to be the preferred reinforcer. The preference for 113 is unknown, however, various performance measures, including the overall response rates from hen 113, do not appear to be inconsistent with the other hens.

The overall response rates found in the current experiment reflect those found by Foster et al. (2009), showing the least preferred food (PW) produced higher overall response rates than the more preferred food (W), at low FR values.

Interestingly, Jackson (2011) found very little difference in overall response rates for W and PW, when hens responded on FR schedules across the different feed types. Jackson (2011) did however plot the mean of the median overall response rates, for series 1 and 2 of her data. This use of the median response rate across inter-reinforcement intervals rather than using the rate over the whole session, is unlikely to account for the lack of discernible difference found. Jackson's overall response rates were very similar — but slightly lower — to those found in the current experiment. Jackson's (2011) overall response rates were approximately 60 per minute, whereas the current study found the overall response rates were around 80 per minute at low FR values. A significant difference in the two methodologies was the session termination criteria. Jackson's methodology states that sessions terminated after 40 reinforcers were obtained, or when 2400-s key time had elapsed. There was no limit to the number of reinforcers that could be obtained in a single 40 minute session in the current experiment. Further research should be conducted to investigate this as a possible contribution to the different results.

In the current research the body weight criterion did not have a consistent effect on overall response rates. Ferguson and Paule (1997) found differences in rat's overall response rates, PRPs, and consumption on PR schedules under various body weights between 70 - 100% of their free-feeding weight. They recorded a decrease in the overall response rate as body weight was increased, as well as a decrease in consumption and an increase in PRP length. Although the subjects were rats, and PR schedules were used, similar results might have been expected here when the hens' weights varied. Weights differed more in the W conditions, specifically at low FR values. Therefore, it might be expected that the lower overall response rates would be seen at low FR values for Condition 1 when compared to Condition 3, when hens were run only in weight range. However, the current findings did not show such a difference.

This difference in findings between the two studies could be from the methodology. Ferguson and Paule (1997) used PR schedules rather than FR schedules. Jackson (2011), however, found no differences between FR and PR schedules; the difference in the schedule is therefore not likely to account for why Ferguson and Paule's (1997) results differ from those found in the current study. The different body weight criteria had very little influence on the actual body weight, as previously mentioned. It may then be that greater differences in body weight are needed to determine the effects of body weight on overall response rates.

In the present study, the running response rates decreased for both feed types, as the FR value increased. This is consistent with Lim (2010), Jackson (2010), and Foster et al.'s (2009) findings. Furthermore, the current results showed that when running response rates decreased, this decrease tended to be steeper for PW than W. Both Jackson (2011) and Foster et al. (2010) reported that running response rates for W and PW decreased at approximately the same rate as FR increased. In the current study, the PW conditions generally had higher running response rates than W conditions at low FR values, but there were higher running response rates for W than for PW at higher FR values. Lim (2010) investigated demand for different feeds in hens, maintained at 80 ± 5% of their free-feeding body weights, and found similar data for running response rates with W and PW, at low FR values. She found that running response rates were higher for W than those for PW, at higher FR values, which was also found the current study. The running response rates at low FR values were slightly higher in the current experiment, compared to those which Lim (2010) found.

Foster et al. (2009) found that the running response rates were similar between W and PW for most of their hens; a result which is inconsistent with the current study. Jackson (2011) also found no difference in running response rates between the two feeds when hens responded on FR schedules. This is also different from the present findings.

In summary, although the body weight criteria in Jackson's (2011) study, Lim's (2010) study and Conditions 3 and 4 of the current study were similar, Jackson used different session termination criteria. It could be that this influenced the running response rates, and further research into session termination criteria may be useful to determine whether this is the cause of these differing results.

Although some similarities were found in running response rates between Foster et al. (2009), Lim (2010), and the current study, Foster et al. (2009) and Lim (2010) found running response rates that were lower overall for the different food types, to the results from the current study. These studies had similar body weight criteria. In addition, the current study found no difference in running response rates between feeds when the body weight criteria differed. It is therefore not clear why the present study produced higher running response rates. Additional investigation may be necessary in order to explain the differences between the present study, and the results from Foster et al. (2009), and those from Lim (2010).

Post-reinforcement pauses

In the present study, altering the food type influenced the mean PRP length at each ratio. The average PRP length was shorter for PW compared to W, at small FR values. An increase in PRP length was seen in PW conditions at the high FR values, whereas little trend was seen in the W conditions.

Felton and Lyon (1966) found increases in PRP length as the FR value increased in pigeons. They also found that as the ratio requirement increased, that there was a decrease in the overall rates of responding, and a corresponding increase in PRP length. The increases that Felton and Lyon (1966) observed at high FR values were similar to the increases that were observed in the PW conditions, in the present study. Crossman et al. (1987) also found that as the FR requirement increased, there was an increase in the average length of PRP times, when pigeons responded for food reinforcement.

The present study found much larger increases in PRP length for PW, than the increases for W, as FR increased. In comparison, Jackson (2011) reported no difference between PRP lengths in PR or FR schedules across the two feeds, in hens. Jackson (2011) found that the average PRP length increased for both food types, as the ratio increased; results similar to those reported by Felton and Lyon (1966) and Foster, Kinloch and Poling (2011).

Foster, Kinloch and Poling (2011) investigated the differences in demand when hens responded under FR schedules for wheat, under various session lengths. They looked at different measures of FR behaviour including PRPs. They found a general increase in PRP duration as the FR requirement increased. This increase was seen in each different condition, but it was largest in the condition that had the longer session time of 120 minutes. The increases were smallest for the shortest session time of 10 minutes. The increases in PRP duration seen in the condition which terminated after 40 minutes were considerably longer than those seen in the current study, where hens also responded for W for 40 minutes. Foster et al. (2011) found these increases to be over 25-s in length in most hens, and up to 80-s, for W. The current study found shorter increases in PRP length of approximately 10 - 20-s long when hens responded for W.

Foster et al. (2009) found differences in the PRP lengths between different feed types, with those in the W conditions being longer than those in the PW conditions. Their results showed PRP lengths of less than 20-s in PW conditions, and generally between 20-40-s for W conditions. These short PRPs are consistent with the results for both feeds at low FR values in the current study. The current research, however, found shorter PRPs in the W condition compared to those in the PW condition. This finding is inconsistent with the findings of Foster et al. (2009). Foster et al. (2009) suggested that it was the increase in the PRP duration in the W condition, that gave rise to changes in the overall response rates found, as previously mentioned. There was no apparent relationship between the overall response rates and the PRP lengths in the present study.

Lim (2010) found increases in the average PRP length in PW and W, as did Foster et al. (2009) and the current study. Lim found that as the ratio requirement increased, the average PRP length also increased. She found that these increases were much greater when hens responded for PW than when they responded for W. She found that when hens responded for PW, the PRP lengths increased to over 100-s at higher FR values. This is similar to the increases in PRP lengths found in Condition 4 (PW) of the present study, where the body weight criterion was strict.

In the present study, the increases in the average PRP durations were greater in Condition 4, than they were in Condition 2, although PW was the reinforcer in both of these conditions. When body weight criterion was relaxed, the increases were approximately 30-80-s in length. When body weight criterion was strict, the pause lengths were longer than 120-s — an increase of over 100-s — for three of the six hens. The increases that were observed in Condition 2 (PW) of the present study, where body weight was relaxed, were of similar size to those seen by Jackson (2011) for both feed types. These increases ranged between approximately 20 - 40-s in duration.

The difference between the increases in PRP lengths in the two PW conditions is interesting, because no consistent differences were seen in PRP length between the two W conditions. This is surprising, as the body weights did not vary greatly between these two PW conditions, as previously mentioned. The difference in the actual body weights of the hens was greater between the two W conditions. Therefore, if the increase in PRP length was influenced by body weight, it would be expected that the average PRP length would differ more substantially in the W conditions at low FR values, where body weights were most different. This could indicate a degree of variability in PRP lengths at high FR values. More research could be conducted in order to identify whether or not there is an underlying cause that has not yet been identified.

In conclusion, it is unclear why the present study found similar results for PRP length increases to Lim (2010) in Condition 4, but not in Condition 2. Furthermore, it is unknown why these results differed from those found by Foster et al. (2009) and Jackson (2011). PRP lengths appear to vary across the studies presented, and therefore, more investigation needs to be conducted, in order to determine the influence that different food types have on the average PRP length.

Demand

When the consumption for the demand function was measured by the number of reinforcers obtained, demand was initially flat, and then decreased, as the ratio requirement increased. The mixed elasticity in the demand function is seen when the overall response rate increase, then decrease, as found in this present study. Such functions are commonly found in animal studies, where demand is assessed (e.g. Foltin, 1992, 1994; Hursh, 1984; Foster et al., 2009; Jackson, 2011).

In the current study, comparing the demand using the reinforcers obtained, showed a difference between feed types. This difference was consistent between Conditions 1 and 2, and conditions 3 and 4. The initial consumption of PW was higher than W at low FR values. At higher FR values, more W was consumed than PW. Foster et al. (2009) found similar results using the reinforcers obtained, with the initial consumption being higher in PW, than for W. As the ratio requirement increased, the consumption of W became higher than that of PW, and therefore, the functions produced look similar to those presented in the current study.

Jackson (2011) found no difference in the shape of the demand functions when using the consumption rate of reinforcers, between the two feeds, when hens responded on either PR or FR schedules. Jackson (2011) needed to use this measure of consumption, as session length varied over the low FR values. Lim (2010) found, using the number of reinforcers as the consumption measure that hens obtained more PW reinforcers than W reinforcers at low FR values, as also seen in the present study. Lim also found that consumption decreased as the FR ratio increased, until there was virtually no difference in demand for the two feeds at high FR values. This is similar to the current findings, though the present study found that slightly more W reinforcers were obtained than PW reinforcers at high FR values. Note that Foster et al. (2009), Lim (2010), and the present study used sessions that terminated after 40 minutes of key time. Had the consumption rate been calculated instead — which would mean simply mean dividing each consumption measure by a constant — the demand analyses would have produced similar shaped functions to those produced with the number of reinforcers.

There were no differences in the findings for the two different body weight criteria, when consumption was measured by the number of reinforcers obtained. Jackson (2011) concluded that it was possible to attribute the lack of difference in consumption of the two reinforcers to low body weights, when comparing her data with that of Foster et al. (2009), who used slightly higher body weight criteria. The criteria used in the current study resulted in body weights that were very similar — if not lower, when strict body weight criterion was implemented — to those found by Jackson (2011). The lack of difference therefore, between the demand functions for W and PW, found by Jackson (2011) was not due to the way in which body weight was controlled, which she proposed.

Demand functions were produced with the weight of food consumed used as the consumption measure. This also resulted in a difference between feed types. Consumption of W was higher than that of PW, consistently across all ratio requirements. This finding was consistent with Lim's (2010) results. In summary, the findings from the current study both reflect the fact that although the hens gained more PW reinforcers, each PW reinforcer weighed less than each W reinforcer.

Analysis of the demand data involved using two equations to compare and contrast the results. Firstly, the consumption data — both reinforcers obtained and amount eaten in grams — was analysed using Hursh et al.'s (1988) equation (Equation 1), by fitting the parameters ln *L*, *b,* and *a* to the data. Secondly, data were analysed using Hursh and Silberberg's (2008) equation (Equation 3), as they argued that the value of a reinforcer could be determined by a single parameter (α).

When Hursh et al.'s (1988) equation was fitted using the number of reinforcers obtained, the initial consumption (Ln *L*) was higher for PW over W. The initial elasticity (*b*) of demand was lower for PW over W. There was no difference in the deceleration of the slope (*a*) across conditions. P_{max} values, calculated using Equation 2, were generally higher for the W conditions compared to the PW conditions. There were no consistent differences across the different body weight criteria in any of the previously mentioned parameter values.

Lim (2010) fitted Hursh et al.'s (1988) equation to her data, using the number of reinforcers obtained as the consumption measure. She also found the initial consumption was higher for PW than W, and that W had larger P_{max} values than PW. Her results were consistent with the current findings.

Foster et al. (2009) found that when analysing the consumption of reinforcers obtained, the initial consumption (ln *L)* was lower for W — the most preferred feed — over HPW and PW, which were both less preferred. Their results showed P_{max} values that were higher for W, compared to PW and HPW. They also found no consistent systematic changes in the parameters *a* and *b* across feed types. The results of Foster et al. (2009) are also similar to the results produced in this experiment, in regards to P_{max} values and ln *L*. In the current study, no consistent differences were found in the parameter *a*. However, a difference was seen in *b*, where *b* was higher in W conditions and lower in PW conditions.

Jackson (2011) found contrary results to Foster et al. (2009) and the present study, when analysing demand functions across feed types. As previously mentioned, Jackson (2011) used reinforcer rate as the consumption measure. This was required because her session lengths varied in the FR conditions, at low FR values. Jackson (2011) found that with both PR and FR schedules, there were no differences resulting from reinforcer types for ln *L* (initial consumption), *b* (elasticity), and *a* (deceleration of the slope) when Hursh et al.'s (1988) equation was fitted to her data. Jackson (2011) concluded that neither the type of reinforcer, nor the individual hens' preference had an influence on her experiment.

Jackson's (2011) difference could not be attributed to a lack of preference between the feeds. Jackson found PW was the least preferred feed, a similar result to those of Foster et al. (2009) and the present study. Furthermore, Jackson's experiment with FR schedules parallels the current experiment in the methodology, except for the session termination criteria. In Jackson's (2011) third experiment, using FR schedules, the sessions terminated after 40 reinforcers or 40 minutes. Given this difference in results, session termination criteria should be further investigated in order to ascertain whether or not this influences demand functions for different feeds.

In the current study, when Hursh et al.'s (1988) equation was fitted to the weight of reinforcers. The results showed that the initial consumption was lower in the PW conditions compared to the initial consumption in the W conditions. There was no difference in either the initial elasticity of the demand or the deceleration of the slope across the different food types. The P_{max} values were found to be higher in the W conditions compared to those in the PW conditions. There were no consistent differences across the different body weight criteria in any of the previously mentioned parameter values. These results are similar to those which Lim (2010) found in her study. Lim (2010) found the initial consumption was higher for W than it was for PW, and that W produced larger P_{max} values than PW. This indicates that W was the more valued reinforcer, as the behaviour persisted at a higher rate, and to larger FR values. The differences in the initial level of consumption for the weight of amount consumed differed from that for the number of reinforcers. Lim (2010) pointed out that conclusions drawn from the analysis depended on the measure of consumption used.

Analysis of the weight of the amount consumed meets the expectations of how functions are expected to look. Based on the results from the preference assessments, it would be expected that the initial consumption higher would be higher for W compared to PW, and P_{max} values would be larger for W than the values for PW. These expectations are consistent with the findings in both the current study and those which Lim (2010) found. For the current experiment, the analysis of the amount eaten could be conducted; this is not always the case. In most cases, reinforcers cannot be measured on a common scale, though, in the present study both reinforcers could be measured in weight. Such a common measure would not be available for many reinforcers. Specifically, it would not be an option when comparing reinforcers that are qualitatively different, e.g. when comparing dust bathing and food reinforcers, dust bathing cannot be weighed as a consumption measure. We need to be able to understand demand functions when the only metric available is the number of accesses earned. There are several ways of normalizing demand for these cases. The most frequently used method is presently Hursh and Silberberg's (2008) approach.

Hursh and Silberberg (2008) provide a single measure of 'value', which is independent of the scalar value of the reinforcer. However, using the Hursh and Silberberg (2008) analysis, Cassidy and Dallery (2012) found unpredicted differences in essential value, under open economy conditions. They found that the larger reinforcer having a lower essential value than the smaller reinforcer. However, this should not have differed with two reinforcers that only differed in size. In these conditions, Cassidy and Dallery (2012) strictly controlled body weight. This difference disappeared when body weight was less strictly controlled in the closed economy sessions. Thus, a second aim of the present study was to fit the Hursh and Silberberg (2008) analysis to the demand data, to see how essential value was affected by the way body weight was controlled, when one food was preferred to the other.

When the Hursh and Silberberg (2008) equation, Equation 3, was fitted to the number of reinforcers from the present study, the findings showed that Q_0 — comparable to the initial consumption measure ln L — was higher in the PW conditions than it was for the W conditions. The α was lower for PW compared to W during relaxed body weight criteria, indicating the essential value is higher for PW than W. Interestingly, however, the results showed that α increased when strict body weight criteria was enforced, and therefore a decrease in the essential value was seen for PW compared to that of W. As body weight was the most different between Conditions 1 and 3, the α values was compared between these, which revealed that α was higher in Condition 1 than in Condition 3. The α values were higher in Condition 4, than in Condition 2, where body weights were very similar. Therefore, the reason for this may not be body weight criteria. Further investigation is needed to examine which factors influence α.

Foster et al. (2009) found that α was consistently larger for W compared to PW, regardless of the k parameter value. Larger values in α are more consistent with the results of the current research, when strict body weight criteria was enforced. Foster et al. (2009) also found larger P_{max} values, which is also consistent with the findings from the present study. Larger P_{max} values for W, compared to those for PW, are consistent with the previous demand analysis.

Hursh and Silberberg's (2008) equation (Equation 3) was also fitted to the amount eaten data. These results showed that when price is at its lowest, consumption (Q_0) was higher in the W conditions to that in the PW conditions. Alpha (α) was consistently higher in the PW conditions (2 and 4), showing less essential value compared to the W conditions (1 and 3). The P_{max}, and P_{max} normalised values, were also higher in the W conditions, compared to those in the PW conditions, similar to the overall results found by Equation 1. This indicates that W has more essential value when weight of food was used as the consumption measure.

In Lim's (2010) study, when the weight of food was used as the consumption measure, ln Q_0 values were higher for W compared to PW, and α values were smaller for W than for PW. Furthermore, Lim (2010) found that the P_{max} values were larger for W, suggesting that W was more favourable over PW, because it maintained the behaviour longer. These results are consistent with the current findings.

Furthermore, in the Hursh and Silberberg (2008) equation, the scaling parameter k can be set to a specific value, or set so it can vary to produce a better fit to the data. It has to be constant across conditions to allow for α to be compared across the demand functions for each condition. The parameter *k* allows for changes in alpha to be observed, and it is based on the range of consumption. The issue is which value of *k* should be selected for an analysis. There are two options suggested by Hursh and Silberberg (2008); it can be calculated using the maximum range of consumption over all data sets, or as the average range of the consumption over all of the data sets. The spreadsheet used for these calculations, as provided by Hursh and Silberberg (2008), suggests using the maximum range of consumption for conditions that are expected to be of similar elasticity and suggest using the average range of consumption for conditions that have scalar differences, i.e. multiple doses of the same drug. Since it was not clear if qualitatively different feeds should be counted as simply different in scalar value or not, the present fits where done using *k* calculated in both of these ways, to see which best described the data. The results showed that both methods produced the same overall conclusions, although the obtained parameter values did differ.

Comparing the parameter values when using the number of reinforcers obtained as the consumption measure, and with *k* set as both the maximum and the average range of consumption, initial consumption was higher in PW conditions compared to W conditions. Furthermore, α was higher for W in five of the six hens, compared to PW when body weight conditions were relaxed. When body weight criteria was strict, however, the α was higher PW compared to W. The parameters Q_0 and α were higher when *k* was measured by the average range of consumption. The parameter *k* was higher when the maximum range of consumption was used, however, the *RSE* values show that using the average range of consumption provided a better fit to data, as these values were higher when *k* was calculated using the average range of consumption.

Lim (2010) also fitted Hursh and Silberberg's (2008) exponential equation to her data for both consumption measures. This equation is a similar equation to Equation 3 — used in the current experiment — however it standardises the price. Lim (2010) allowed k to vary and also set it to 3.5 and 6.5 manually, for both measures of consumption. Her results showed that when k was set manually at either 3.5 or 6.5, the initial consumption values were higher for PW than those for W, and α values were smaller for W than PW when the measure of consumption was the number of reinforcers.

When the parameter values were calculated using the amount eaten as the consumption measure, they revealed that the initial consumption (Q_0) was higher for W than PW and that α values were lower in W conditions compared to those in the PW conditions. Additionally, the P_{max} and normalised P_{max} values were higher for W than they were for PW. The parameter values for Q_0 and α were higher for when the average range of consumption was used to calculate the parameters. The parameter k was lower when the average of the range of consumption was used. In addition, the *RSE* values were higher when the average range of the consumption was used, which indicates the function fits the data better when k is calculated in this particular way.

In Lim's (2010) study, when the weight of food was used as the consumption measure, W gave higher ln Q_0 comparatively to PW, and the value of α was smaller for W than PW. She also found that P_{max} values were larger for W than they were for PW. She let the parameter k vary, the results of which were so variable that manually setting k would not adequately fit the data. Lim (2010) therefore believes that α is not a reliable measure to assess the relative value of a reinforcer, as it is affected by the value of k.

Foster et al. (2009) — who preceded Lim (2010) — also reported the influence of *k* on the essential value measure, α. Foster et al. (2009) found that the results of the normalization process were influenced by the *k* value used. Foster et al. (2009) found that a higher *k* value (8.0) resulted in smaller α values, indicating a higher essential value for PW, compared to that of HPW and W. As it appears that the essential value is so easily influenced by *k*, it is worth investigating a more stable and robust measure of the relative value of reinforcers.

Cassidy and Dallery (2012) fitted Hursh and Silberberg's exponential equation to the data of rats responding on increasing FR schedules, for access to one or two pellets of food. They were comparing demand under open economy sessions that ran for 130 minutes, and closed economy sessions which ran for 23 hours. They found differences in the demand curves from the two session types, for the two different amounts of reinforcers.

Cassidy and Dallery (2012) found that consumption decreased as FR increased, like in the present study. They found fewer reinforcers were obtained when the rats were responding for two pellets, compared to when they were responding for only one pellet. Furthermore, an increase in consumption was seen in the closed economy, which was attributed to both session length, and the economy type.

Cassidy and Dallery (2012) found that by setting *k* to 3, in order to observe the changes in α between conditions that differed in reinforcer magnitude, the functions were similar in shape. This indicated that the essential value was the same between these conditions. The α parameter decreased in conditions that differed in magnitude, therefore, a decrease in the essential value was suspected. Interestingly, however, more variation in the α values were seen in the one pellet conditions. Additionally, the α values were not significantly difference across the economy types. This indicates the type of economy, and subsequently session length, did not influence the essential value; however, reinforcer magnitude can influence α.

This indicates that different factors can influence the essential value of a commodity, such as magnitude, and how *k* is calculated. The *k* parameter can be set, or left free to vary using either the average range or maximum range of consumption, based on either the reinforcers differ in scalar value or expected to change in elasticity. A problem is that reinforcers can be both. Altering how *k* is calculated produces differing values for α, and therefore indicates that it may not be a robust measure to assess the relative value of reinforcers against one another.

In conclusion, results were compared to previous research namely Lim (2009), Jackson (2011), and Foster et al. (2009). These studies were similar to the current research project, where hens responded on a series of ascending FR schedules. One main difference between the research of Jackson (2011), and Foster et al. (2009) was the body weight criteria. In any performance measures investigated, specifically breakpoints, overall response rates, running response rates, and the average PRP length, there were no consistent differences found between Conditions 1 and 3 (both W), and Conditions 2 and 4 (both PW), when the different body weight criteria was compared.

Additionally, there was no difference found between the demand functions produced by Conditions 1 and 3 (both W), and Conditions 2 and 4 (both PW). This indicates different body weight criteria do not have a significant influence on performance or demand measures. There was a difference in the α parameter values, however, when Hursh and Silberberg's (2008) equation was fitted to the number of reinforcers obtained data. Fitting this equation, revealed that α values were lower for PW compared to those for W, during relaxed body weight criteria, but α values were higher for PW than those for W, when strict body weight criteria was enforced. This finding should be further investigated.

A second difference in previous research procedures is that Jackson (2011) had different session termination to Foster et al. (2009), Lim (2010), and the present experiment. This could explain why her results differed in many aspects, particularly demand for different feed types. Therefore, it is proposed that the experiment is replicated with more similar methodology to Jackson's (2011) research, in order to investigate whether changing the session termination criteria will result in demand functions being similar for the two feed types, like those found by Jackson (2011).

Experiment 2

Method

Subjects

Experiment 2 was conducted using the same six Brown Shaver hens (*gallus gallus domesticus*) numbered 111 to 116.

Apparatus

The apparatus used in experiment two was the same as that used in Experiment 1, including the chamber, scales and magazine which were located in the same place. The computer attached to the power supply and magazine was located in the same room and also ran the MedPC program like in Experiment 1.

Procedure

The procedure was similar to Experiment 1 using PW and W. Hens responded on a geometric progression of FR values for 2-s timed access to food. Sessions were terminated after 40 reinforcers were received, or after 2400-s of key time excluding the magazine operation time. The series would continue until no reinforcers were delivered in a session. If no reinforcers were obtained during a session, the hen would be exposed to that particular FR value again. In the following session, if no reinforcement was obtained again, that was considered to be the end of that series. In the case that reinforcement was obtained, the sequence would continue in the following session until two consecutive days of no reinforcement at which point the series was then stopped like that in Experiment 1. Preceding the experimental data collection the hens would be exposed to an FR 40 schedule for at least three days. The food presented during this period was contingent on what was being provided in the next condition.

In Condition 1 hens were placed in the experimental chamber only if they were in weight range which was 80 ± 5% of their free-feeding weight. The hens were responding for PW. FR schedules were presented one per session, in an ascending order starting at FR 1, and followed a geometric progression. Following this, the hens were exposed an FR 40 schedule for several sessions, until all hens had finished the series. They then responded on an FR 40 schedule for three days for W prior to Condition 2.

Condition 2 was identical to Condition 1, except for the food placed in the magazine hopper. In this condition, the food that was used was W.

Results

The summary data from each experimental session in each of the two conditions alongside the data from Experiment 1 are presented in the Appendix, located inside the back cover.

Breakpoints

The FR value at which the series terminated for all hens is presented below in Table 8. The breakpoints were typically between FR values 256 and 1024, with the majority of breakpoints being FR 256. Four of six hens had the same breakpoints in both conditions. Two hens had slightly higher breakpoints in the W conditions compared to PW.

Table 8. The last FR requirement presented before responding ceased for each of the six hens for both conditions in Experiment 2.

	Condition 1 PW	Condition 2 W
111	256	256
112	256	256
113	512	1024
114	512	512
115	256	256
116	256	512

Response rates

The overall response rate was calculated as in Experiment 1, with the total number of responses per session divided by the key time (2400-s). Figure 29 shows the overall response rates across both conditions for all six hens plotted against the natural logarithm of the FR value. The overall response rates increased, peaked and then decreased as the FR schedule increased. Figure 29 shows that response rates in Condition 2 (W) were slightly lower at the low FR values than those in Condition 1 and response rates were higher Condition 1 (PW) compared to Condition 2 (W) at the higher FR values. The differences at low FR values were small for Hens 112 -115.

The running response rate was calculated as it was in Experiment 1.Figure 30 shows the running response rates plotted against the natural logarithm of the FR values for both conditions. No running response rate can be calculated for FR 1 so this is omitted from the Figure. The running response rates decreased as FR value increased. There was no consistent difference between the data from Condition 1 (PW) and Condition 2 (W) for all hens.

Post-reinforcement pauses

The average PRP time was calculated as it was in Experiment 1. Figure 31 shows the average PRP length across both conditions plotted against the natural logarithm of the FR values. The average PRP was shorter at low FR values than at higher FR values. Figure 31 shows the PRP lengths are very similar across the two conditions, until an increase at high FR values. The increase in pause duration was particularly prominent in five of the six hens, with a pause length of more than 80-s in the PW condition (Condition 1). Hen 114 shows slight increases in both conditions, with the PRP durations being slightly longer in the PW condition than those in the W condition, but the average PRP length was generally shorter than the increases for other hens.

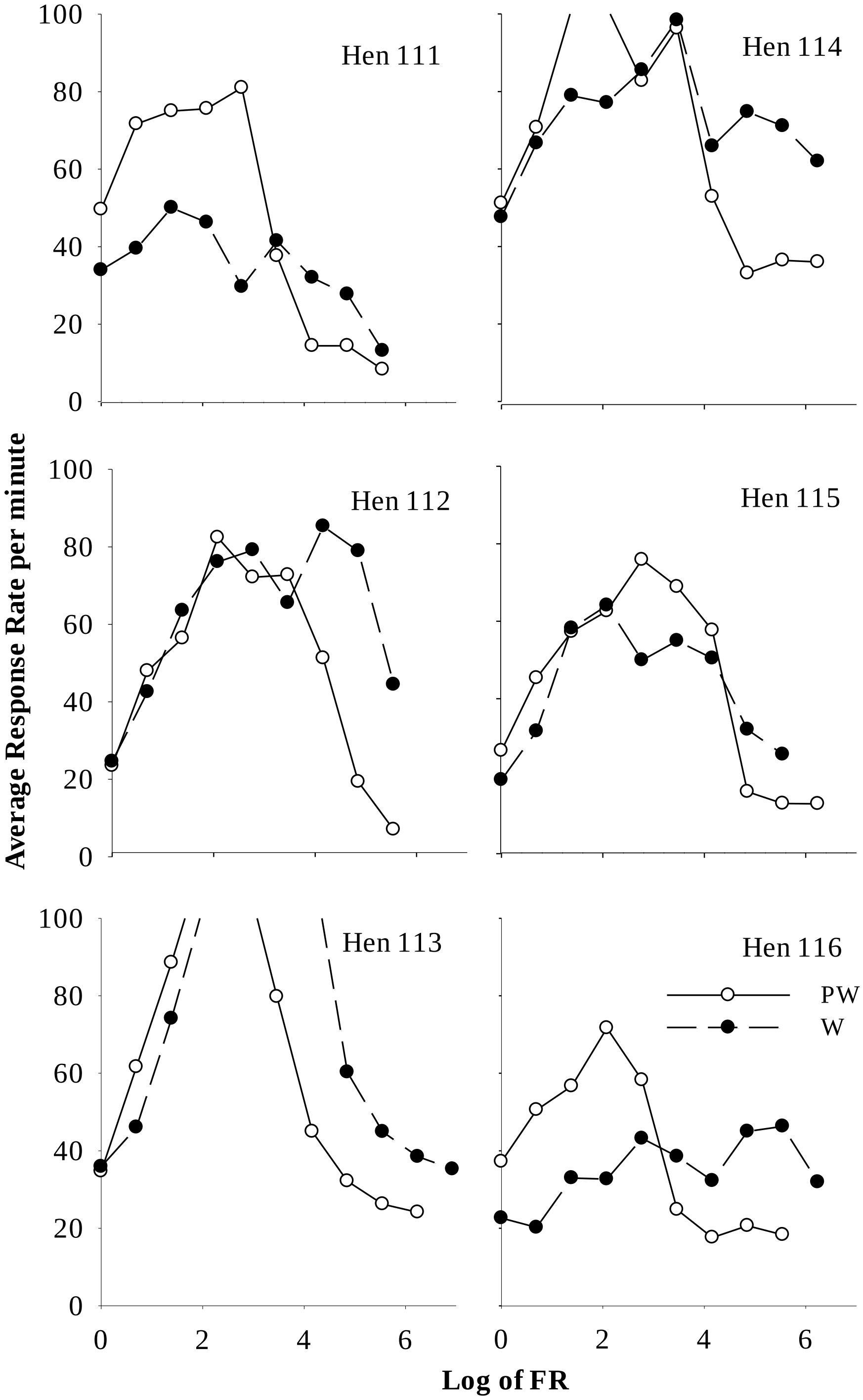

Figure 29. This graph shows the overall response rates for each FR schedules for Conditions 1 and 2 for each hen.

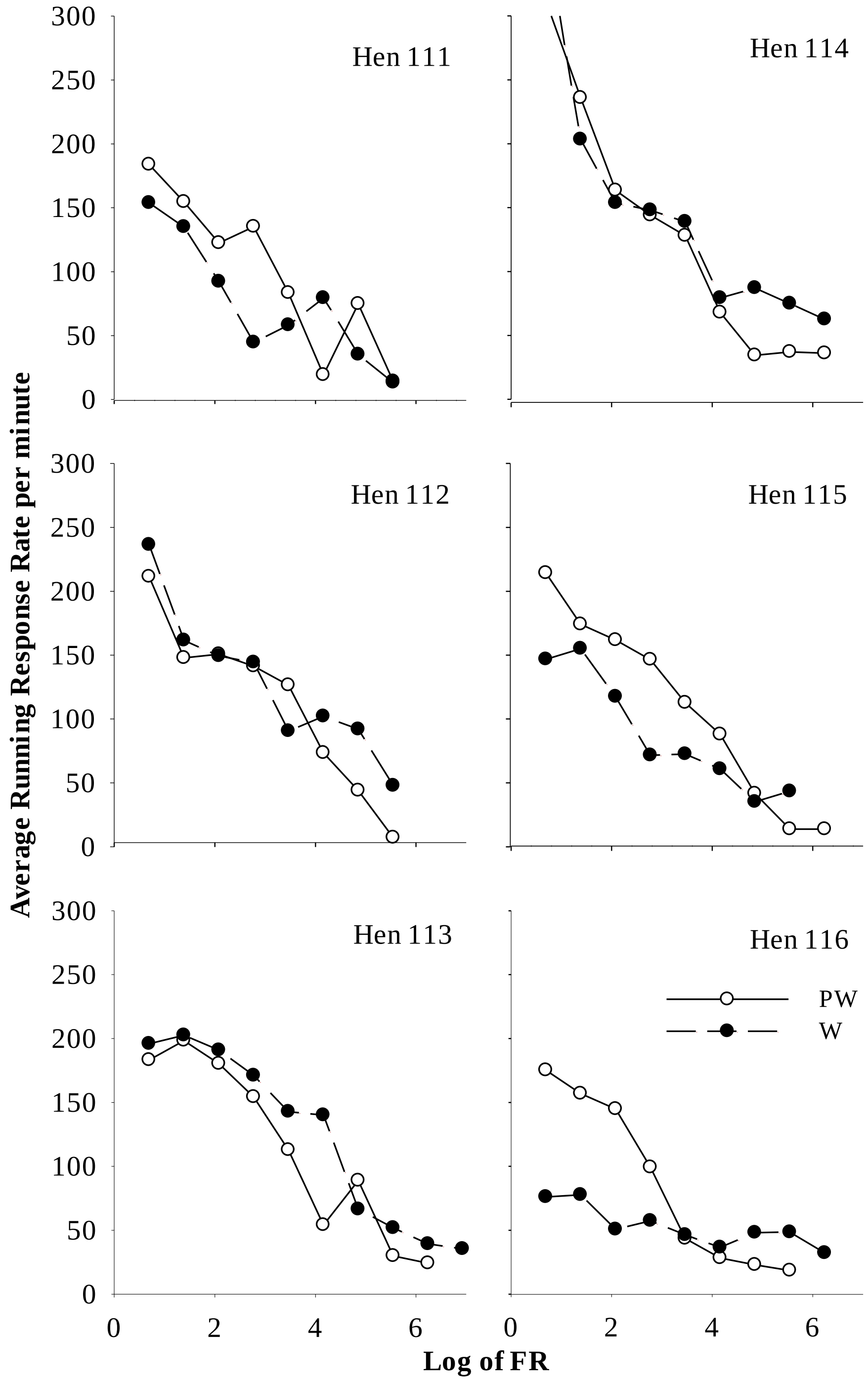

Figure 30. This graph shows the running response rates for each FR schedules for Conditions 1 and 2 for each hen.

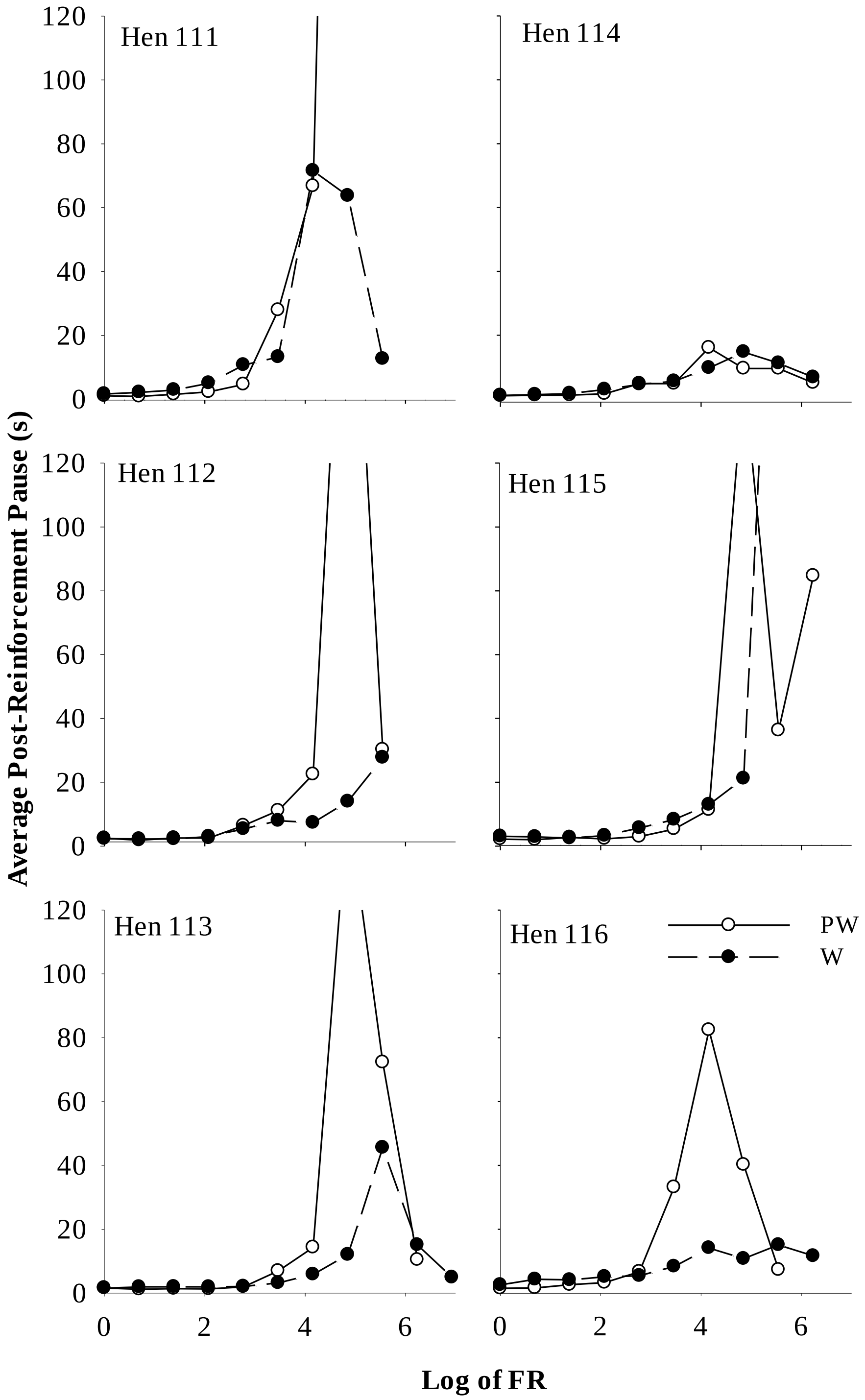

Figure 31. This graph shows the average post-reinforcement pause duration for each FR schedule for Conditions 1 and 2 for each hen.

Demand

The consumption rate was calculated by dividing the reinforcers obtained per session by the total key time. Figure 32 shows the natural logarithm of the consumption rate for reinforcers is plotted against the natural logarithm of the FR values. The consumption rate decreased as the FR value increased consumption rates for the two different feeds were very similar for three hens at low FR values. For the other three hens, consumption rates were very slightly higher in PW than they were for W. At high FR values there was a difference in consumption rates between the feed types. In five hens, the consumption rate was higher for W compared to PW at high FR values.

Additionally, the natural logarithm of the amount eaten data was graphed. Figure 33 shows the natural logarithm of amount eaten (weight) for W and PW plotted against the natural logarithm of the FR values. This graph shows higher consumption rates for W compared to PW at all FR values in all six hens. Consumption appeared relatively stable at low FR values, up until approximately FR 64 where the consumption decreases, the point in which all 40 reinforcers are no longer being obtained.

Hursh et al.'s (1988)'s equation (Equation 1) was also fitted to the consumption rate data. Table 9 lists values which indicate the initial consumption (indicated by the ln *L* values) were higher for PW, the parameter *b* was higher in PW whereas *a* was lower in PW compared to W. The *RSE* values show the functions fit the data well. P_{max} values were very similar for the different feeds in three hens, whereas in the remaining three, P_{max} was higher for W than PW in two hens and higher for PW than W in one hen.

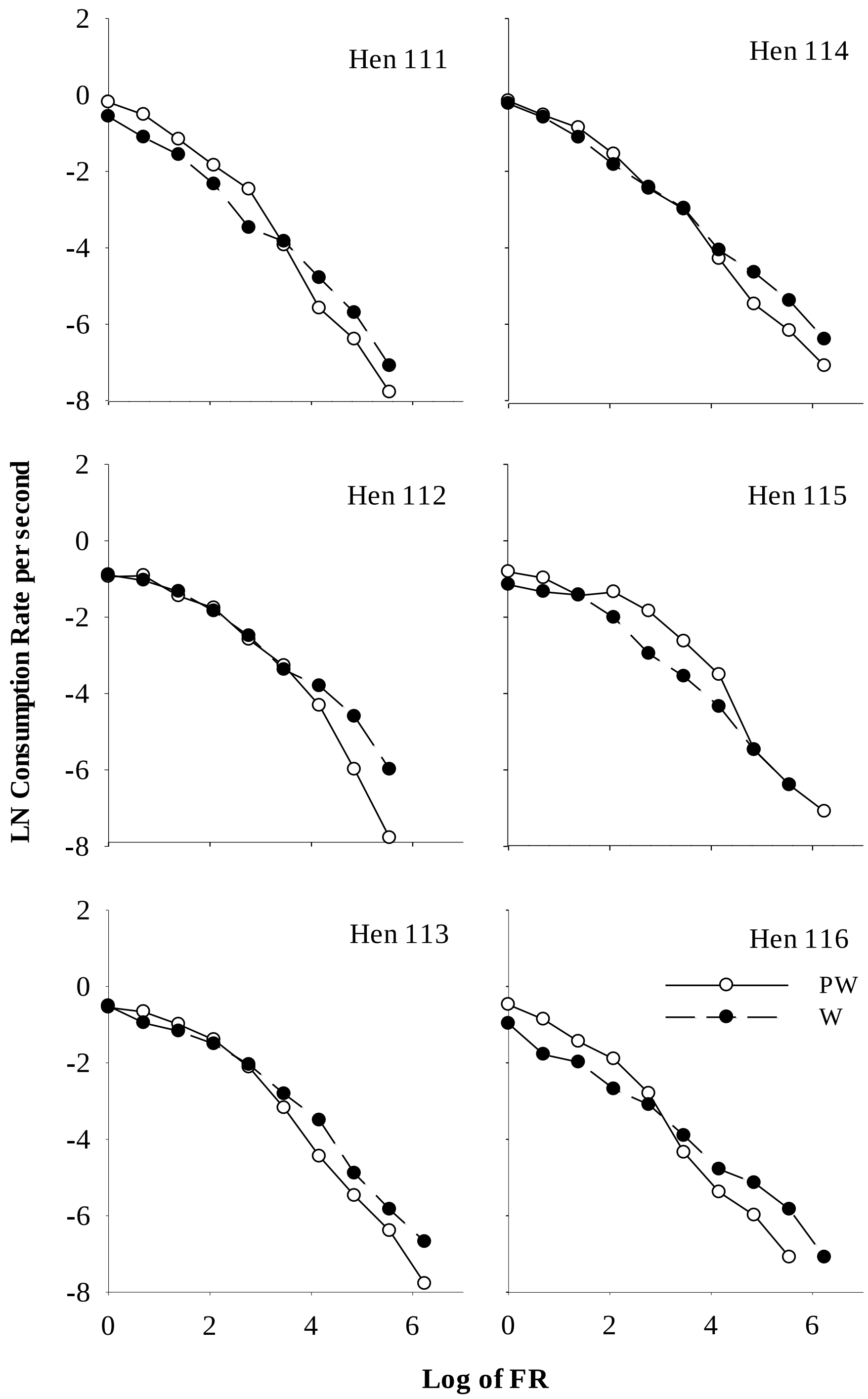

Figure 32. This graph shows natural logarithm of the consumption rate using reinforcers obtained for each FR requirement for Conditions 1 and 2 for each hen.

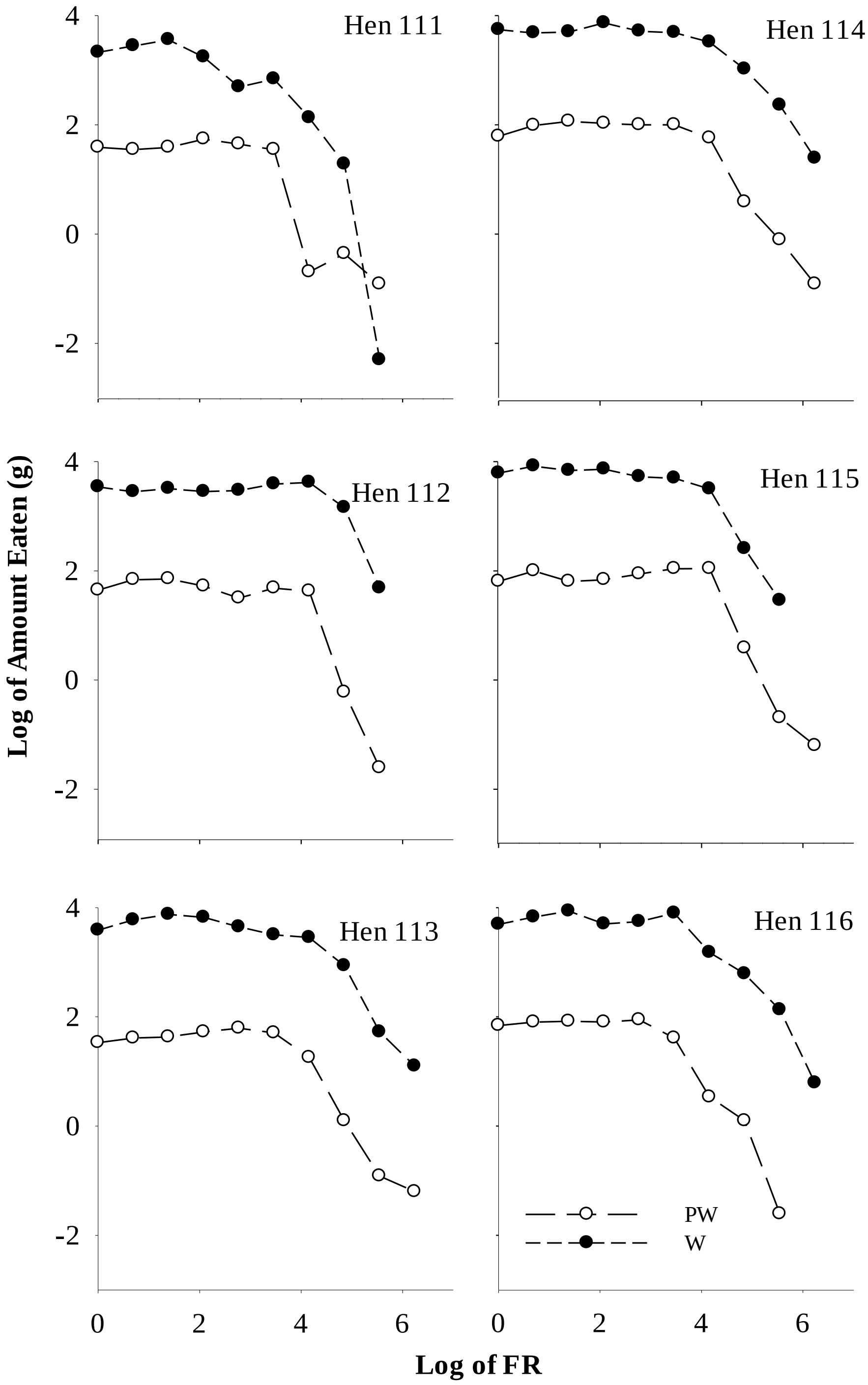

Figure 33. This graph shows the log of the weight of food consumed under each FR schedule for Conditions 1 and 2 for each hen.

Table 9. This table shows the parameters ln *L*, *b* and, *a* produced when Equation 1 was fitted to the consumption rate of reinforcers, for each hen. The residual standard error of the estimates (*RSE*) and *%VAC* and P_{max} are also presented.

			ln L	***b***	***a***	***RSE***	***%VAC***	***Pmax***
Hen 111	1	PW	0.72	-0.23	-0.0023	0.09	92.71	98.56
	2	W	0.46	-0.15	-0.0015	0.07	89.79	96.17
Hen 112	1	PW	0.41	-0.11	-0.0009	0.04	96.25	123.93
	2	W	0.41	-0.11	-0.0009	0.03	98.07	123.46
Hen 113	1	PW	0.54	-0.13	-0.0004	0.06	94.15	338.38
	2	W	0.49	-0.11	-0.0003	0.06	93.03	346.94
Hen 114	1	PW	0.72	-0.20	-0.0011	0.10	92.09	178.68
	2	W	0.65	-0.18	-0.0010	0.10	89.52	176.06
Hen 115	1	PW	0.43	-0.10	-0.0004	0.03	97.51	246.19
	2	W	0.32	-0.09	-0.0007	0.03	96.95	125.73
Hen 116	1	PW	0.53	-0.17	-0.0017	0.06	93.55	99.99
	2	W	0.27	-0.07	-0.0004	0.06	82.50	174.13

The consumption rate of reinforcers per minute was analysed using Hursh and Silberberg's (2008) equation (Equation 3). The parameters Q_0, k and α were calculated and are presented in Table 10. Table 10 shows higher Q_0 in PW compared to W and higher α in PW compared to W in five of six hens. The parameter k was constant across all conditions, and all hens. The P_{max} values and the normalised P_{max} values were higher for W compared to PW. Furthermore, the *RSE* shows that the functions fit the data well.

Weights

The daily body weights were also recorded. Figures 34 and 35 show the weight (in grams) for each hen across Condition 1 and 2. The weights are shown from the start of the series, until the last FR value at which the hen terminated the series. The individualized target weights for each hen are shown which were calculated as 80 ± 5% of their free-feeding weight like Experiment 1, and are indicated by the horizontal lines. Both Figures 34 and 35 show that hens rarely fell outside of the target body weight range, in either condition.

Table 10. This table shows the parameters Q_0, k and α calculated when Hursh and Silberberg's (2008) equation (Equation 3) was fitted to the number of reinforcers, when k was calculated by the average range of consumption. The table also includes the residual standard error of the estimates (*RSE*) and P_{max}, and $P_{\max}$ normalised are also presented.

	Condition		Q_0	α	k	RSE	Pmax	Pmax[Normalised]
Hen 111	1	PW	44.11	0.000434	3.26	0.98	8.29	3.66
	2	W	14.43	0.000543	3.26	0.89	20.26	2.92
Hen 112	1	PW	19.59	0.000612	2.80	0.99	15.62	3.06
	2	W	15.53	0.000404	2.80	0.93	29.88	4.64
Hen 113	1	PW	31.68	0.000270	3.35	0.96	18.13	5.74
	2	W	23.54	0.000195	3.35	0.93	33.82	7.96
Hen 114	1	PW	44.54	0.000297	3.04	0.96	12.89	5.74
	2	W	21.69	0.000245	3.04	0.86	32.08	6.96
Hen 115	1	PW	23.92	0.000392	2.70	1.00	20.80	4.97
	2	W	15.83	0.000628	2.70	0.95	19.62	3.11
Hen 116	1	PW	42.10	0.000589	2.96	0.97	7.09	2.98
	2	W	7.01	0.000546	2.96	0.84	45.92	3.22

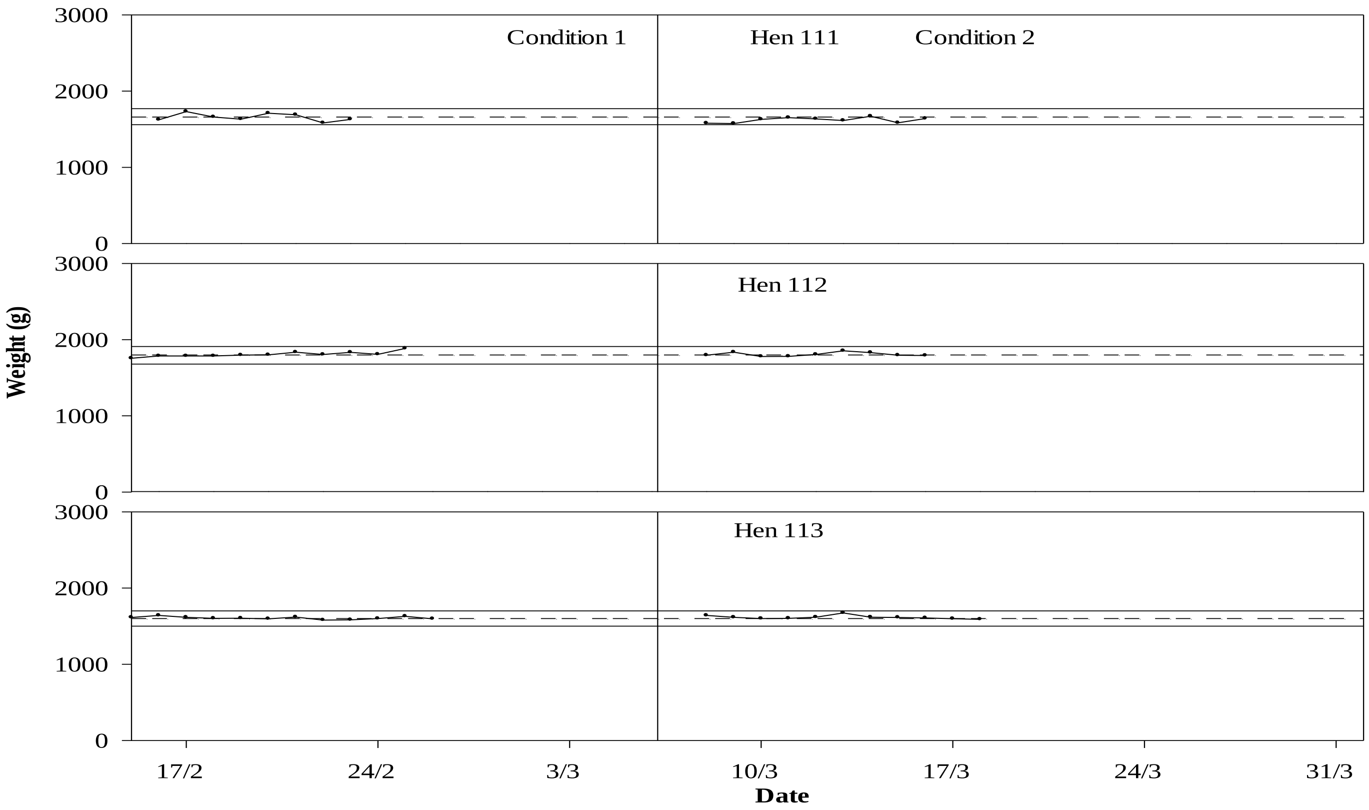

Figure 34. This graph shows the daily body weights for Experiment 2 for hens 111, 112 and 113.

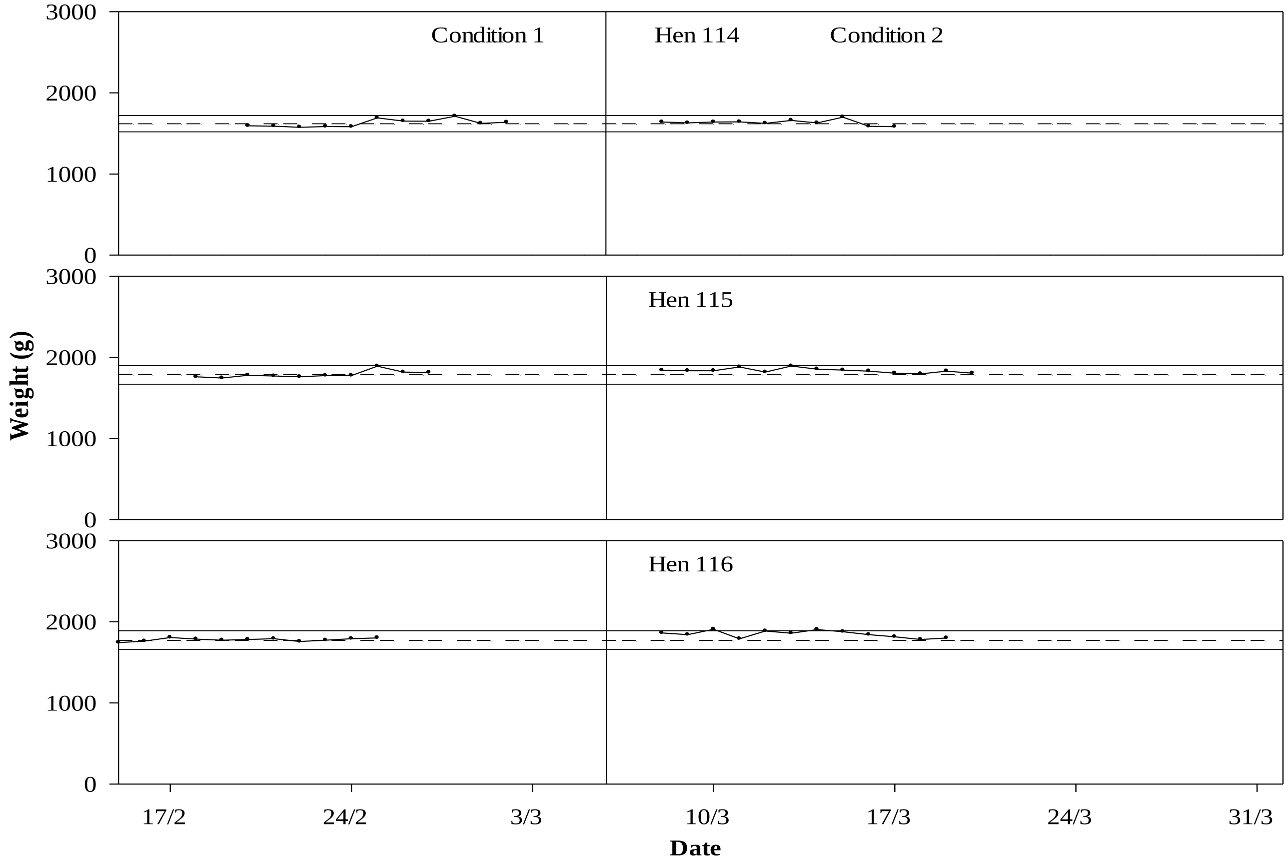

Figure 35. This graph shows the daily body weights for Experiment 2 for hens 114, 115 and 116.

Discussion

The aim of this experiment was to examine whether or not different session termination criteria affected performance and demand, for two different feeds in hens. Jackson (2011) found no difference in demand for W and PW when hens responded on a series of ascending FR schedules, whereas, previous studies have found a difference in demand for these feeds (e.g. Foster et al., 2009; Lim, 2010). The current research aimed to evaluate the hypothesis that this difference in results could be caused by a difference in session termination criteria, as Jackson (2011) used sessions that ended after 40 reinforcers were obtained, or after 2400-s of key time. Foster et al. (2009) and Lim (2010) ended sessions at 2400-s key time, without a limit of the number of reinforcers that could be obtained in a session. Experiment 2, therefore replicated the methodology used by Jackson (2011). Like Experiment 1, hens responded on a geometric progression of ascending FR values for 2-s access to W or PW. One series was run in both conditions. Hens were required to be within the target body weight range of 80 ± 5 % of their feeding weight for both conditions. Sessions terminated after 40 reinforcers were obtained, or 2400-s of key time, whichever was achieved first. The results showed that there were differences between two the feeds in breakpoints, overall response rates, running response rates, PRP durations, and demand.

Hens were within the target weight range for the duration of both conditions. For this experiment, the point at which the hens terminated the series was always between FR 256 – 1024. These FR values are consistent with Experiment 1, and those found by Foster et al. (2009), Lim (2010), and Jackson

(2011). The current results showed that there were very little differences in the breakpoints between feed types. There was a slight tendency for breakpoints to occur at higher FR values in the W conditions, compared to those observed in the PW conditions. This finding is consistent with previous research which found breakpoints are slightly higher in W conditions compared to the PW conditions (e.g. Foster et al., 2009; Jackson, 2011; Lim 2010).

The overall response rates increased as the FR value increased, before they peaked at over 70 responses per minute, then decreased again. The overall response rates were higher for PW than they were for W at low FR values, for five hens. In three of these five hens, this difference was, however, very small. Additionally, five hens had considerably lower overall response rates for PW compared to those for W, at low FR values. The findings from Experiment 1 showed that the overall response rates were higher for PW than they were for W at low FR values, but lower for PW than they were for W at higher FR values; a finding similar to those of the present experiment. Foster et al. (2009) also reported higher overall response rates for the lesser preferred food (PW), than for the more preferred food (W), at low FR values. Additionally, Jackson (2011) found very little difference between the overall response rates for W and PW, when hens responded on FR schedules under similar conditions. There is no obvious explanation for this, as the methodologies between Jackson's (2011) experiment and the current experiment are almost identical. The only difference is that Jackson (2011) used body weight criteria of 80 ± 10 %, whereas the current study used the criteria of 80 ± 5 % of the hen's free feeding body weights. This slight difference should not account for the different findings in the overall response rates.

The running response rate was higher for PW than it was for W, in three hens at low FR values. The running response rates, however, were higher for W, compared to those for PW, at low FR values in the other three hens. Hens 112, 113, and 114, showed very similar running response rates at lower FR values. When the running response rates increased, at higher FR values in these hens, the running response rates were higher in the W conditions than those in the PW conditions. Five hens showed higher response rates at the higher FR values when they responded for W, compared to when they responded for PW. One hen (111) almost consistently showed higher running response rates when responding for PW rather than W, with the exception of FR 64. The overall pattern of decreasing running response rates is consistent with the findings from Experiment 1. The results from Experiment 1 showed higher running response rates for PW compared to those for W at low FR values, and higher running response rates for W at high FR values, compared to those seen for PW. This is similar to what is seen in the current results.

In the current results, where the hens had higher running response rates for W compared to those for PW, at low FR values, this difference between the two feeds was very small. Where the running response rates were higher for PW than those for W, at low FR values, there was a considerable difference seen. Furthermore, it is worth mentioning that the height of these functions was similar in both experiments. This finding shows that running response rates are not influenced by session termination criteria in this experiment.

Jackson, (2011) Lim (2010), and Foster et al. (2009) all found that running response rates decrease, as the ratio requirement increases. Foster et al. (2009), and Lim (2010) both found that the running response rates were higher for PW than they were for W, at low FR values. The running response rates were, however, higher for W than they were for PW at higher FR values. This is similar to the results of three hens in the current research. Foster et al. (2009) and Lim (2010) both had response rates that were slightly lower than those found in the current experiment. These were, however, consistent with Experiment 1.

Jackson (2011) found no difference in running response rates between the two feeds when hens responded on FR schedules. The current experiment showed very little difference in three hens at low FR values. It may be worth further investigating session termination length, to explore whether any consistent differences are found in running response rates between the two feed types.

The average durations of the PRPs were also examined. The PRP lengths were relatively stable at low FR values, before increasing steeply at high FR values. A number of studies have also seen an increase in PRP length, as ratio requirement was increased (e.g. Felton & Lyon, 1966; Crossman et al., 1987; Foster et al., 1997; Foster et al., 2009; Lim, 2010; Jackson, 2011).

The PRP lengths tended to increase at high FR values, and then decrease steeply. The durations of these increases in the PW condition identified in the current findings are similar to those increases observed in Condition 4 — where body weight was under the same strict control and hens were responding for PW — in Experiment 1. The increases that were observed showed that the PRP durations were longer for PW compared to those for W, at higher FR values, a finding that Jackson (2011) had previously noted. These increases in the average PRP length are longer in duration than those identified in Experiment 1, for either W condition.

Jackson (2011) found that when PRP increased in her experiment, for both feed types, the durations were not as long as those observed in the current experiment. This could indicate that different session termination criteria are not the variable that was affecting the average PRP length, in different feed types. Both the current experiment and Jackson's had the same session termination criteria, but produced slightly different findings. There is no perceived explanation for these differences.

The demand was calculated in a different way from Experiment 1. In the current experiment, consumption rate was measured instead of consumption. This is because of the fact that limiting the number of reinforcers that could be obtained in a session, would have affected the results had the number of reinforcers been used as the consumption measure. When reinforcers were used to calculate consumption rate, results of the current experiment show very little difference in demand for W and PW. There is very little difference in three hens, and small differences in demand between feeds in the other three hens. At low FR values, less difference is seen between the feed types than at higher FR values. At higher FR values, five hens showed higher consumption rate for W, the preferred food. Hen 115 showed no difference in consumption at the last three FR values.

Jackson (2011) also measured consumption using reinforcer rate and found similar results. She found no difference in demand when hens responded for W and PW under ascending FR values where the session terminated after 40 reinforcers, or 40 minutes of key time (2400-s).

Jackson's (2011) results differed from previous research conducted by Foster et al. (2009) and Lim (2010). Jackson (2011) had suggested that this difference in results was attributed to the differences in body weight criteria between the two studies. This theory was later relinquished after Experiment 1, where a difference was found in demand between food types in conditions where body weight was relaxed, and in conditions where body weight was strict. The results from the present study showed that the difference in session termination criteria in the respective methodologies was a possible that the reason Jackson found no difference in demand between W and PW.

When the amount of food consumed was analysed, the results showed that there was higher consumption of W than of PW, at all FR values in all six hens. This is consistent with Experiment 1, and previous research by Lim (2010).

Equation 1 (Hursh et al., 1988) was fitted to the data using rate of reinforcement as the measure of consumption.The results showed that the initial consumption (ln *L*) was higher for PW compared to that of W. Initial consumption rates were consistent with the findings from Experiment 1, Lim (2010), and those results found by Foster et al. (2009). These differences between feeds were, however, a lot smaller than those observed in Experiment 1. Jackson's (2011) data did not show a consistent difference in the initial consumption between the two feeds.

The current results showed that the initial elasticity (*b*) was higher in PW than it was for W, and the rates of change in the slope (*a*) were smaller for PW compared to those for W. These findings differ from the findings of Experiment 1. Jackson (2011), and Foster et al. (2009) found no consistent systematic changes in the parameters *a* and *b* across feed types. This is also different than the findings from the current experiment, which found consistent, but small, differences between the two feeds.

Furthermore, the current results revealed no consistent difference in the P_{max} values, unlike Experiment 1 which found higher P_{max} values in the W conditions, compared to those calculated for the PW conditions. Lim (2010) and Foster et al. (2009) also showed higher P_{max} values in W compared to PW.

It is unclear why the results from this study differ from those of Jackson (2011), in regards to the parameter values, as the methodology was almost identical. The only difference is that Jackson (2011) used the body weight criteria of 80 ± 10% of the hens' free-feeding weights, whereas the current experiment used body weight criteria of 80 ± 5% of the free feedings weights. Body weights were lower in the current experiment compared those found in Jackson's experiment, however, Experiment 1 found no difference in relaxed or strict body weight criteria for these parameter values. It is noted that the parameter values were, however, more consistent in the present study with those that Jackson (2011) found than those produced in Experiment 1.

Additionally, consumption rate of reinforcers per minute was analysed using Hursh and Silberberg's (2008) exponential equation. The results showed that Q_0 values were higher for PW compared to those for W. This finding is consistent with the results from Experiment 1, and those from Foster et al. (2009). The present study found that α was higher for PW compared W, indicating that the essential value of PW was lower than that of W. Experiment 1 showed that when strict body weight criteria was implemented — like the current experiment — the α values were higher for PW than those for W. These findings were inconsistent with those that Foster et al. (2009) found.

In addition, the Hursh and Silberberg (2008) analysis showed that there were no consistent differences in P_{max} values between the two feeds, in the current experiment. This is not consistent with the findings from Experiment 1, which found P_{max} values were generally higher in the W conditions, like Foster et al.

(2009). In summary, these findings suggest that strict body weight control may influence the alpha parameter for the two feeds, as this was consistent between the two studies. It is unclear why the P_{max} values for W and PW did not reflect previous findings.

The current research only used one series in each condition. To further explore the possibility that session termination criteria effects demand for different feeds, this experiment should be replicated to provide further evidence in support of this theory. Following this, it may be useful to include economy type and session length into further research. The session durations were impacted in the current research where reinforcers were limited to 40 per session. This meant that at the smaller FR values, hens obtained 40 reinforcers, and the session ended well before 2400-s. It would be interesting to conduct further analysis to explore the impacts of different session lengths and their effects on behavioural performance, and demand, under FR schedules for different feeds.

Furthermore, Cassidy and Dallery (2012) have already investigated rats responding on increasing FR schedules for access to different magnitudes of food. The open economy sessions ran for 130 minutes, and supplementary feeding was provided when necessary. The closed economy sessions ran for 23 hours with no provisional feeding. Rats were maintained at approximately 85% of their free-feeding body weights, and they were not placed in a session if overweight, in the open economy. In the closed economy session no post-feed was offered thus weight could vary. Cassidy and Dallery (2012) found that essential value was lowest for the two pellets and highest for one pellet under the open economy; an unexpected finding, but the difference in essential value was not statistically significant under the closed economy. This indicated that the demand functions were affected by either the different body weight control, or by the different economy types, or by both. Due to the experiment, body weight could be safely discarded from further investigation, and therefore the focus should fall primarily on the way in which economy type influences demand and essential value.

General Discussion

The first aim of the current research was to examine the influence of body weight on demand for food. The first two conditions of Experiment 1 used similar methodology to Foster et al. (2009) where hens were run even when they were above the body weight criteria. In the following, two conditions similar methodology to Jackson (2011) was used, where hens had to meet the body weight range of 80 ± 5 % of their free feeding weight. The results from Experiment 1 showed the criterion used did not change the shape of the demand function, or consumption of each food types.

A second aim was to examine how essential value, a measure proposed by Hursh and Silberberg (2008), was affected by the way body weight was controlled and by food type. When consumption was measured by the number of reinforcers obtained, the α value indicated changes in essential value between body criteria conditions. When the body weight criterion was relaxed, α was lower for PW compared to W. When the strict body weight criterion was enforced, however, α was higher for PW compared to W.

Body weight itself then was not seen as an explanation for the differences in results between Foster et al. (2009), Lim (2010) and Jackson (2011). Therefore, a second experiment was carried out, where sessions terminated after 40 reinforcers were obtained, or after 40 minutes of key time had elapsed. The key finding from this study revealed that demand for feed types appeared to be influenced by session termination criteria. There were no consistent differences in demand for the two feeds, which is consistent with what Jackson (2011) found. The difference in session termination criteria therefore is a possible explanation for why Jackson's results were different from previous research.

One of the limitations with the procedure of these experiments was that the changes in body weight were not strictly controlled or analysed as closely as they were in Hodos' (1961) study, or that of Furgeson and Paule (1997). The body weights in the present study varied the most in the first two conditions of Experiment 1 at low FR values, and therefore the most difference in performance measures, and initial consumption, would be seen at low FR values. Interestingly, no consistent differences were seen at low FR values between conditions that had different body weight criteria.

What is required now is a more systematic approach to vary weights between 80 - 100% of free-feeding body weights, with strict requirements of meeting target weights. This would give a better overall indication of how body weight affects performance measures and demand across all FR values for different feeds. The α values should be examined due to the changes in essential value between W and PW, when body weight was under different criteria, as previously discussed.

In the present study, although, the value of α changed, dependent on how *k* was calculated, it must be noted that the overall conclusions did not change. As pointed out by Foster et al. (2009), Lim (2010) and Cassidy and Dallery (2012), α is influenced by multiple variables. Studies use differing *k* values, either setting them (e.g. Foster et al., 2009; Lim, 2010) or using the maximum or average range of consumption to measure *k* (e.g. Foster et al., 2009) which influences α. As the calculation of *k* alters the value of α, more recommendations should be added to the analysis procedures on the best practice to ensure results can be compared across studies.

As already discussed, another proposed idea is that the second experiment from this research should be replicated. Experiment 2 replicated the results of Jackson (2011), but only one series was conducted. In order to improve the generality of these results, several series should be conducted to ensure consistency between results.

Alternatively, a study where session lengths are examined would be beneficial. It would be interesting to use similar methodology to Foster, Kinloch and Poling (2011) with strict body weight control with different food reinforcers, i.e. W and PW. The current experiment found that limiting the reinforcers to 40, resulted in shorter session lengths at low FR values. At higher FR values, sessions would run for the full 40 minutes as not all 40 reinforcers were obtained. The proposed research would therefore eliminate the possibility of session lengths being the cause of the lack of difference between demand for the two feeds.

Additionally, it would be interesting to further investigate the effect of economy type on demand. As previously mentioned, Cassidy and Dallery (2012) handled body weight differently in each different economic condition. In the open economy, body weight was controlled with the use of post-session feeding, whereas in the closed economy, body weight was more variable as there was no post-session feed available. They found that the essential value was lowest for two pellets, compared to one pellet in the open economy, but they were not significantly different in the closed economy. Thus, essential value was affected by body weight control, or economy type, or both. As the results of the current study indicate body weight does not considerably influence the shape of the demand function, but rather the α values. Further research of effects of economy type on demand should be investigated.

In conclusion, the current study found that body weight criteria did have some effect on demand for the two different types of feeds, wheat and puffed wheat. There was a difference between demand for W and PW but no difference in demand functions were noted between the differing body weight criteria. Hens responded more for PW than W at low FR values in Experiment 1, though gained less PW reinforcers than W when measured by weight. In Experiment 2, under the same body weight criteria as the third and fourth conditions in Experiment 1, the results showed that there was a tendency for this difference in demand, between feeds, to be reduced. Furthermore, the current study also found the essential value, as indicated by the value of α, of these reinforcers was influenced by body weight criteria. The results of Experiment 2 showed that changing the session termination criteria to 40 reinforcers, or 40 minutes of key time, eliminated the difference in demand for the two feeds. Further research should include the effects of session length, and open and closed economies on demand for food. Moreover, future research should investigate changing body weight systematically, to determine the effect on demand for food in hens, and also the effect on α. It is also proposed that a more stable and universal analysis of demand should be used as α is easily influenced by the way in which *k* is measured.

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